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The AMERICAN PHYSICS TEACHER

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Graduate Preparation for a Career in Physics

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THE aims of a program of postgraduate study differ fundamentally from those of an undergraduate program. Undergraduate physics instruction in the typical liberal arts college is carried on primarily by a series of formal lecture and laboratory courses designed to introduce a student to the fundamental principles of the science, and to sketch the broad generalities and applications of the scientific method. The program is seasoned with a description of those particular phenomena which by reason of their important applications or the spectacular nature of their effects make an immediate appeal to the interest of an average student. If the undergraduate program is part of an engineering curriculum a much larger amount of technical material is usually included in order to cooperate effectively with the various engineering faculties.

Among the graduate aims, on the other hand, I would put first the furtherance of physical science by the training of able investigators. The medieval ideal of the acquisition of knowledge for its own sake is admittedly narrow and sterile, but the history of the past hundred years has shown beyond cavil the fruitfulness of pure scientific investigation. Our present position on the road toward "the more abundant life" has not been reached in a legislative vehicle but on the shoulders of gifted original thinkers and investigators. Nor have we any evidence that future progress can be made by any other means. These original investigators must not only discover the way but carry us the greater portion of the distance along it. Genius is rare, and there are no rules for its training. But it is the function of the university to help discover and to attract able and original men, and as teachers of physics it is our duty to give them the background of the present status of the science, to indicate the outstanding problems, to provide them with all the facilities at our disposal, and above all to encourage and stimulate their initiative. I do not mean to imply that what we ordinarily mean by the word "scholarship" should not also be encouraged. A real contribution is made by those encyclopedic minds that furnish us with handbooks and bibliographies, by the historian who traces the development of the science, and by the writer who organizes a field of knowledge into a treatise. These are the fruits of maturity that ripen in the scholar and represent a line of future development rather than an immediate and primary aim of graduate training.

We must also train teachers to follow along and take our places. Here again the problem is not an easy one for the teaching even of a science is an art. The truly inspiring teacher, of whom we can all recall examples, probably is born rather than made. But even in an art, perfection can be achieved only by a thorough knowledge of the fundamentals together with a single-hearted devotion to the subject. In addition there must be unremitting practice, carried on by an open and inquiring mind that is able to perceive and develop new and promising technics. Again the goal should be not only to expound physical facts, principles,

and methods, but to nurture the pioneering and inventive spirit. It is also important for any scientist and particularly so for a teacher of a science that he should be able to stand up before his colleagues and students, and deliver himself in a clear and convincing way. The cerebral machinery must continue to revolve when he is in an upright position, with a minimum exhaust of "ahs" and "ums" and few vibrations or twitchings of the manual and pedal extremities.

Finally we must equip the large number of men who go out to fill technical positions in industry. The chemists have preceded us in this field and have a more firmly established position in industry as a whole. As yet only the most farsighted and progressive industries have established laboratories for physical research. But eventually the field for the physicist is the larger of the two for almost all engineering is merely applied physics. If we can supply men having the proper training and initiative there will be an ever increasing demand for them in all technical enterprises. These men must not be mere compendiums of technical information; handbooks serve that purpose. They must be not only well trained in the science but well aware of its scope. They should be ready to explore any region in their vast field. Admittedly they cannot be authorities in all branches but they should be equipped to learn them independently and efficiently. They must be able to study and understand unfamiliar problems, and to design suitable methods of attack that will yield the maximum of information. They must correlate their experimental results and perceive their useful applications. In short, they must be men of energy and initiative with both a training in scientific analysis and the ability to perform the necessary industrial synthesis. In addition the industrial scientist must understand the spirit and the art of cooperation. He must cooperate not only with his fellow scientists but with technicians, engineers and executives if he is to fulfill his calling; and he must never give the impression that he is being called louder than anyone else.

It is important to realize that many of these desiderata cannot be imparted at all and that the majority of the remainder are learned rather than taught. There are first of all the necessary social qualities such as integrity, intellectual honesty, and so forth without which no man can be really successful in any profession. These cannot and should not have to be taught to a graduate student though he can be confirmed in them by his scientific associates. Similarly one cannot impart the simple animal energy necessary for the pursuance of a successful career and for the prosecution of a theoretical or experimental program in the face of difficulty and discouragement. Industry and cooperation can be encouraged but not lectured upon. An undivided interest in one's chosen field is essential to a successful career. Here we are most fortunate in physics, for a single-hearted devotion to the practice of such a fascinating science germinates in the student when he perceives the beautiful processes of induction leading to physical laws and of logical deduction of new lines of investigation therefrom. As he continues through a well-planned curriculum until by his own efforts and initiative his research is contributing new knowledge, this enthusiasm will take root and will continue to grow and be fruitful as long as he is free to follow a scientific career. This view of physics as both profession and hobby, vocation and avocation, is not so much the studied objective of a teaching program as it is the inevitable result of a firm grasp of the subject, stimulating instructors and colleagues, and an untrammeled initiative. As for the scientific insight necessary to perceive promising lines of investigation and the significance of the results achieved, it is learned by actual experience. Similarly, the mental and manual dexterity that a scientific worker must possess is gained only by long practice. Since there is no substitute for experience and practice in achieving these most important ends, it is probable that the formal lecture program receives too much weight in the average graduate curriculum.

Now we may consider the practical methods of graduate training within the limits that have been implied here. Various tools are used which fall more or less into three categories. These are: (1) formal lectures, classes, and laboratory work, (2) seminars and colloquiums, with the preparation and presentation of papers, and (3) individual research problems and theses. These probably are listed in the inverse order of

their importance. More lasting benefit accrues to a student from contact with able investigators and association with an active research group than from any formal presentation of subject matter. But the most important feature is the student's own personal contribution to the work in progress. As in everything else the sum total of his final development varies directly with the effort that he has expended. The "constant of proportionality" is determined by the wisdom with which his program is chosen and the facilities at his disposal. No matter how favorable these factors are, however, little can be accomplished unless every effort is bent to stimulate his interest and bring out his ability to undertake and solve his own problems.

The important functions of lectures and laboratory instruction are to help the graduate student gain insight into the fundamental divisions of his subject, to introduce him in more detail to the status of those phases in which his own work is to lie, and to acquaint him thoroughly with the general technic of laboratory manipulation. To these ends graduate lectures might well be of two general types. There are those courses of lectures that cover certain fundamental subjects with which every advanced student of physics should be familiar. It is not possible to give lectures in all the divisions of physics nor is it necessary; for though each of the divisions has its own special problems, there is a fundamental unity running through them all. The concept of energy and its transformations, the tools of potential theory, the theory of small oscillations, and other mathematical technics, form the links of a chain that unites all the branches of physical theory. Three or four courses of the most fundamental nature may be chosen which will present these fields in the desired detail and at the same time serve as prototypes to indicate how other particular fields should be organized. Incidentally, a well-conceived series of lectures by an able teacher will be long remembered as an inspiration and as an ideal to be approached by men undertaking a teaching career. The choice of subjects to be covered by such lectures may vary somewhat with departmental circumstances, but they might well be: analytical mechanics, electricity and magnetism, quantum mechanics, and atomic physics. These would seem to represent an irreducible minimum and it should be realized that none of them can be treated exhaustively in a year's lecture course.

There is also the other general type of lecture—those that are elective with the student. These are the less formal but more detailed presentations of limited fields by men who are themselves working intensively in them. They are designed to bring the second- or third-year student abreast of the latest developments in those subjects in which his own research or principal interests lie. Such courses are generally given for small and more or less homogeneous group of students and, after a few preliminary lectures, can be conducted more profitably on a seminar basis. This has the double advantage of giving the student an opportunity to formulate and deliver papers and of relieving the instructor of routine lecture preparation. I believe that such a program of organized individual participation and discussion under the direction of a stimulating instructor is the ideal method of conducting a specialized course. It provides experience in the organization of material and in the use of handbooks, bibliographies, abstract journals and the like—tools which are as necessary as any laboratory equipment. Of almost equal importance, it provides the easiest and most effective way to master the art of written and oral presentation of technical material. Such a program does not run itself automatically. The general plan should be organized and supervised with care and the instructor must preserve the proper emphasis, direct the discussion into profitable channels, and encourage the necessary critical atmosphere. The results will then be worth all the effort and an abundance of new suggestions and points of view will emerge from the discussions.

Of similar value are departmental colloquiums in which papers of a more general nature are presented and discussed. A more exacting task is the discussion of current experimental results or the review of a series of journal articles, for a larger synthesis and critical evaluation are necessary and a more finished representation is expected. Subsequent discussion by the group as a whole is often most illuminating. The group aspect is important in the graduate program.

Laboratory equipment can be purchased and books can be borrowed; but a university alone can provide a stimulating group of scientific colleagues, and this is the most educational instrument that has ever been devised. Such groups are the breeding grounds of ideas. Lines of investigation suggest themselves, suitable technics are evolved, and the individual thesis is the natural culmination. A research problem that arises in a seminar group is almost certain to be a suitable and well-thought-out project. It is closely integrated with the previous work in the field and has been planned to make a real contribution to the body of existing knowledge. The direction of an experienced and qualified investigator is available and stimulating discussions with other colleagues often are an invaluable source of suggestion in the course of the undertaking. With this type of training behind him a student is prepared to continue on his own initiative, and to cooperate in any academic or industrial laboratory or become an able and inspiring teacher.

A student should be encouraged to undertake original work at the earliest time that it is feasible. Although this is partly an individual matter and also depends somewhat on the circumstances obtaining in a particular laboratory, a liberal attitude toward permitting the student to try his wings is wiser than one of postponing this phase of his activity until he has acquired a mastery of all the fundamentals. True, in the early stages he will make mistakes, but these will teach him more than anyone else's, and if this most important part of the program is put off too long his development is unnecessarily retarded and the result is frequently stultifying. Often an opportunity presents itself to assist a more advanced student already working on his thesis by taking routine measurements, maintaining equipment, and so forth, or to act as a research assistant to a staff member who has a problem under way. Such an apprenticeship serves as an excellent introduction to research and gives the student a "feel" for experimentation. In such an arrangement he should be encouraged to make all the personal contribution he can and to exercise his initiative to the extent that is compatible with his subordinate role. The problem should of course be appropriate to his interests. If a student has misjudged his proper vocation it will become very evident during this apprenticeship; and it will be a kindness to him to direct him out of physics and into some more congenial occupation, possibly engineering or business. But if he takes hold enthusiastically, one of the many interesting lines of advance that are bound to open up in the course of any project will more often than not provide him in turn with a suitable thesis project. He can then carry this out on his own responsibility with the association and supervision of a member of the staff. In such an arrangement he starts out under circumstances that are most favorable to a successful culmination. He is already familiar with the previous relevant results, is thoroughly acquainted with the experimental technic, and has a well-formulated objective. If, as occasionally happens, the introductory apprenticeship is not feasible he will require more supervision and his progress will be less rapid. A word as to the choice of thesis projects. A problem of long standing that has been attacked unsuccessfully by many previous workers is obviously an unfair task for a beginner; and a routine piece of work that calls for no new ideas and is not a really significant contribution is unworthy of the doctorate. A mean must be struck, and this is arrived at most naturally as a result of seminar discussions or of individual conferences in the course of a research apprenticeship. Once the thesis problem is well under way the supervisor should lighten his touch, assume an advisory role and give free rein to the student's responsibility and initiative. The student must consider the problem as his own if he is to obtain the maximum development and the satisfaction of personal achievement.

There are many other practical matters that need consideration, but a detailed discussion of them must perforce be omitted. If a student undertakes graduate work with an inadequate undergraduate preparation these lacunas must be filled. A knowledge of the routine laboratory technics is essential as is also a reading knowledge of scientific German and French. There should be as wide an acquaintance as possible with the bordering sciences of mathematics and chemistry. Although these are necessary adjuncts they are more or less outside the province of the depart-

ment itself and the best method of acquiring them depends on individual circumstances. Of course these remarks apply in particular to the experimental physicist. The fields of the mathematical physicist and of the physical chemist bridge departmental boundaries and adequate training is necessary in all the departments concerned.

I should like also to stress the value to the student of a wide personal acquaintance among his scientific colleagues and of attendance at meetings of scientific societies. Journal clubs and scientific gatherings will provide him later with the same stimulating atmosphere as his graduate seminars and colloquiums afforded. There are few of us who at any time in life can produce our best work without the close association and encouragement of our scientific colleagues.

Nothing has been said about examinations for these are a part of the creaking machinery rather than of the spirit of a university. The enrolment in a graduate department should be limited and the methods of grading and testing used in large undergraduate courses cannot be justified. In obtaining a preliminary estimate of a student's ability or in the selection of fellowship candidates, examinations may have their place. It may also be argued that a useful purpose is served by the preliminary examinations for the doctorate, which a candidate generally takes after about two years of graduate study and which are designed to test his knowledge of the most essential fields of physics. They are a milestone along the road, where he can set in order the knowledge that he has accumulated; to have passed them successfully is an indication both to himself and to the faculty that he has an adequate grasp of the fundamentals and can safely proceed to specialize in a chosen field. But it is only when the departmental training is inadequate or the student is new that the outcome of an examination cannot be predicted with accuracy. Hence examinations are of dubious value and should be designed to interfere as little as possible with the main objectives of a graduate program. These remarks do not apply to the final public oral examination and the defense of a thesis. This is not an examination in the ordinary sense but a colorful tradition that represents the formal termination of a phase of training; in it the candidate gives public evidence of his fitness to pursue a scientific career.

Nothing has been said about the degrees themselves—the tags with which the products are labeled. The doctor's degree is by general acceptance reserved for those men who have made at least their maiden contribution to scientific knowledge and who are prepared to embark on a creative career. The master's degree is less well defined and is frequently more hedged about with formal requirements. It is a degree that has various significances in different places, but it is generally associated with qualification for teaching in a secondary school. A tendency to be deplored, however, is that of considering this degree as a reward for a man who has tried unsuccessfully to carry through the larger program that has been here envisaged. This appears most regrettable to me, for the preliminary stage of the larger program—the attendance on a certain number of formal lectures—has little if any bearing on his ability to teach physics at a preparatory school level. He can be an excellent teacher without it or a poor one with it. The master's degree should have a simple and generally accepted significance of its own, for the school teacher should not be considered as the poor relation of the research scientist. Much could possibly be said for a point of view more closely akin to that of the English universities, where the M.A. is a degree that connotes maturity. Its requisite is often merely the payment of a fee but it usually represents a certain number of years of scholarly pursuit and residence in an academic atmosphere. Interpreted in this way it could fulfill the purpose of a senior degree for the teaching profession. It is unwise to consider it as a step toward the doctorate, for the graduate program leading to this degree is conceived as a whole and must be pursued to the end if it is to fulfill its purpose. This is a high purpose; may we have the wisdom and ability to conceive and administer a program that will increase the rate at which scientific knowledge is advanced and its fruits made available to everyone.

Evaluation of Student Achievement in the Physical Sciences[1]

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WHEN a teacher is faced with the problem of measuring student achievement, he immediately is forced to ask himself the question, "Achievement of what?" Quite often, the measurement of student achievement has been made largely in terms of an approach in which the main goal is to have the student emerge with a knowledge of the facts and principles of physical science. Also, in many cases, these facts and principles are treated in an academic manner with but very little reference to their function in the everyday life of the student. In contrast to this approach another can be made in which the goals of instruction represent those outcomes which the instructor considers to be of vital importance for the student. Interest in a program of evaluation for the physical sciences usually arises from a desire to make the subject matter and methods of these sciences a part of the lives of those who study them. In the development of a program of instruction in which this is true, the physical sciences must not be considered solely as a framework which determines our external environment, but also as a type of thinking which penetrates our entire intellectual atmosphere. They cannot be considered apart from other social, cultural, and educational interests. The physical sciences must not be thought of as existing in a vacuum and differentiated from other manifestations of the human spirit. In the last analysis, they represent that mode of thought which has largely determined our lives and the type of civilization in which we live. Instruction in them should be focused toward a development of this type of thinking rather than on an accumulation of facts about physical phenomena.

In order to answer the question "What do we expect students to achieve in the physical sciences?" we must approach the problem with a clear understanding of the intellectual and cultural pattern from which we have emerged as well as that into which we are moving. We must see that civilized society with its social and economic institutions has arisen as a collective effort of the human mind, reacting on the world of persons and things with human values ultimately in the foreground. Only by keeping these ideas in mind can we hope that the student of the physical sciences will have a real chance to become "a humanist and a humanitarian, a pleasure and a profit to himself, a sagacious leader of his fellows aware of consequences, and a pointer-out of directions." The failure to convey to elementary students some sense of these larger human values is responsible for a good deal of our disappointment and disillusionment concerning the achievement of students in our courses.

It is easy enough to interest a student in the relationship between speed and stopping distance of a modern automobile. It is quite another matter to interest him in the same general problem when it is put in a much more academic fashion; for example, to determine the distance passed over in coming to rest by a particle that has a certain initial speed and a certain deceleration. The former situation is human and intimate; it comes within the range of experience and serves to fulfill a human need with regard to the reduction of accidents. The recent mathematical developments in physics have tended to carry us far into the regions of the abstract, and have tended to remove physics still further from the range of immediate human interests and needs. These developments increase the difficulty of making instruction in physics vital and effective for those who are not looking forward to special-

[1] The philosophy and point of view leading to the work reported in this article have arisen from the attempt to measure the achievement of students in the unified course in physics and astronomy at Ohio State University. The two senior authors have been responsible for the direction of the program. The instruments for evaluating student achievement have been developed by the junior author while working under a General Education Board fellowship. The present article outlines the general approach to the problem. Other papers planned to follow this one will deal in more detail with the technic of making evaluation instruments and with some of the results of the study.

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ization in physics. It thus becomes more imperative to find a way to organize and present introductory courses in physical science so that their outcomes will play an important part in meeting the needs of the student. The central thought in the evaluation of the achievement of students in the physical sciences should always be the integration of an understanding of physical facts with physical thinking in a way that makes them a real part of our human experiences and interests.

Elements of evaluation procedure

How, then, are instructors to proceed in order to organize the content of their courses and to modify their methods of measuring achievement so that they may have some evidence that students have developed an appreciation of the physical world in which they live and some facility in the type of thinking by which we have arrived at our present state of civilization? Evidently instructors must first determine their objectives as clearly as possible and then develop some method of evaluating the progress of students in the attainment of these objectives. It is at this point that difficulties arise. The complexity of the whole situation makes it extremely difficult to formulate objectives which can be stated in terms of observable entities. Moreover, the methods of observing and evaluating the achievement of these objectives are vague and uncertain. The situation is not unlike that which confronted the pioneers of physics before the concepts of time, length, or mass were abstracted out of physical phenomena and standards for their measurements were developed. It seems that real progress cannot be made here until instructors abstract their objectives more precisely and have more trustworthy methods of evaluating the effectiveness of their instruction.

The development of the physical sciences themselves suggests the direction in which we should move. In the solution of a physical problem the first step is the accumulation, by means of experiment and observation, of a mass of accurate data about the phenomena under investigation. The next step is to abstract from these data certain concepts which can be used for the description of the phenomena under consideration. Only those entities may be chosen that can be made the subject of accurate experiment; otherwise conclusive results cannot be obtained. In a perfectly analogous way, if we are to proceed with some certainty in the evaluation of achievement in the physical sciences, we must abstract some objectives, concepts, which are as unambiguous as possible. To serve our purposes, these concepts must be capable of fairly accurate description and measurement. Technics for the necessary observations and methods must be devised. As a first approximation it is possible to isolate those concepts (objectives) which are now implicit in instruction in the physical sciences. If these concepts are so chosen that they can be made the subject of observation, some progress in the evaluation of instruction is possible. In addition the criterions for the attainment of these objectives must be available. These criterions should be activities—thinking or manual—of students which can be observed and in terms of which the attainment of the objectives may be stated.

What are some of the outcomes of physical science instruction? It is easily recognized that the content of what we call physical science is a hybrid of many aspects of thinking, of which factual information is a very important part. But teachers of physical science desire to have students emerge from their courses with something more than factual information of physics, chemistry, or astronomy. They believe, also, that students will come out of these courses with some ability to think clearly. The need for this type of thinking has been emphasized by L. A. Hawkins of the General Electric Research Laboratory in a recent address. He points out that the most important outcome of instruction in a science should be mental training which he defines as clear, logical, and alert thinking. In expressing the need for such training, he said:

> "Untrained minds are unable to cope with the natural emotions and prejudices which sway us all. They cannot free themselves from bias, nor distinguish wishful thinking from the truth. They are unable to weigh evidence, to distinguish fact from appearance, to judge the validity of traditional beliefs, to adjust their thoughts and ideas to rapidly changing conditions. They are an easy prey for the demagogue, the opportunist, and the charlatan."

The type of thinking which we call clear, alert, and logical, is rather difficult to define explicitly.

It must be broken down into its elements. Some science teachers believe that when broken into its elements, it means that a student will be able to draw reasonable inferences from numerical and descriptive data. They also believe that it involves the recognition of assumptions which are implicit in the acceptance of a conclusion drawn from some kind of evidence. Still another phase of this type of thinking is involved in the ability to recognize the fundamental physical principles which underlie common, everyday phenomena. Students who have developed this method of analysis will also be sensitive to the social changes which have arisen from the advances of physical science as well as to the changes in mental habits which have emerged from scientific thinking. These specific aims or objectives partially represent the goals which the teacher may have in mind in the development of clear, logical, and alert thinking.

If the development of the ability for logical and alert thinking and of an understanding of social implications represent primary goals of instruction in the physical sciences, instructors should develop means of instruction and instruments of evaluation of student achievement according to those goals. Only after these goals or objectives are explicitly identified and student achievement in them measured, is it possible to say how much a course in physical science has developed the objectives desired. Too often it has been assumed that achievement in the knowledge of the facts and principles of a science course is an index of the student's ability to think scientifically. The instructors of the departments of botany and zoology at Ohio State University decided that this assumption should be tested. The instructors were not willing to take for granted a high correlation between achievement in factual information and the achievement in several other outcomes which they defined as part of the scientific method. In the development of the general courses in botany and zoology, these instructors focused their attention on a few of the outcomes of their courses which they thought to be most valuable. A knowledge of the facts and principles of botany and zoology, the ability to apply these facts and principles to new situations, and the ability to draw inferences from data, as well as to recognize generalizations in data, represented the primary concern of these teachers. The achievement of students in these areas of greatest concern was measured by means of carefully constructed tests. The results of these tests indicate that: the correlation of the achievement in the knowledge of facts and principles of botany and zoology with the achievement in the ability to apply these facts and principles to new situations was 0.41; the correlation of the ability to interpret data new to the student with the knowledge of the facts and principles was 0.42; the correlation of the ability to interpret new data and the ability to apply the facts and principles of botany and zoology to new situations was 0.38. Experiments made in the unified course in physics and astronomy at Ohio State University in which the same objectives were involved gave somewhat similar results. One is forced to infer that the evaluation of student achievement purely on the basis of factual information is not necessarily an index of his growth in these other areas.

The justification of this inference is made more obvious by considering the procedure in physical science. In physics, for example, it is not customary to use the density of liquids as an index of their viscosities, surface tensions, or boiling points. Instead these quantities are singled out and measured explicitly. It might very well be that a relationship does exist between the density of a liquid and its boiling point, but certainly until the relationship has been demonstrated, it is not safe to assume one and proceed accordingly.

Therefore, in order to measure specifically the changes which instructors desire to produce in the mental habits of their students, we may proceed somewhat as in the analysis of a physics problem; that is, by abstracting those abilities, mental and manual, which at the present time are all thrown together into one heterogeneous group. These desired changes in students represent the aims or the objectives of instructors. After the aims and objectives which are considered to be of vital importance have been selected from the hybrid of activities involved in the study of the physical sciences, it is then necessary for the teacher to decide what the typical student would do if he (the instructor) has been successful in attaining his objectives. These operations, if carefully carried out, make it possible not only to construct tests for demon-

strating the presence or absence of student achievement according to the teacher's aims, but also to devise class activities through which it may be possible to attain these desirable developments.

Objectives and criterions for their measurement

The initial steps in the effort to evaluate student achievement in the unified course in physics and astronomy at Ohio State University centered about the problem of deciding on the objectives of the course. The aims or objectives which the instructors considered to be most important are:

(a) To develop in the student an understanding of the *major ideas* of physics and astronomy through a knowledge of the facts and principles which pertain to the major ideas.

(b) To develop in the student the ability to analyze critically and to interpret data.

(c) To develop in the student the ability to apply the principles of physics and astronomy to situations which are a part of his experience, but in which the principles have previously been obscure.

(d) To develop in the student the ability to recognize the assumptions that underlie certain conclusions which have been drawn on the basis of insufficient data.

These objectives represented the framework of the course. Any phases of physical science that were not relevant to the objectives were to be omitted from the course. After the objectives were thus made explicit, it was necessary for the instructor to indicate what he believed the typical student should do if he (the student) were to have made satisfactory achievement. In this way, the criterions for the measurement of student achievement were established. These criterions will be considered briefly in the following illustrations of objectives.

Interpretation of data. In the unified course in physics and astronomy, the instructors decided that the development of the ability to interpret data represented one of their most important objectives. This ability was construed by the instructors to mean that the student should recognize generalizations which can reasonably be drawn from the data, he should be able to make reasonable inferences on the basis of new data and any other information which he has at his disposal, he should recognize that in making extrapolations he is going beyond the data, and he should exercise caution in implying cause and effect on the basis of correlation. These activities represent the criterions which the instructors use in the measurement of student achievement in the interpretation of data.

The following situation illustrates a typical case in which the student is expected to point out or to indicate the generalizations that can reasonably be drawn from data.

Observations made by Watson in a certain auditorium at the University of Illinois of the strength of sound at various times after it is emitted in the auditorium are as follows:

Intensity or strength (percent of peak value)	Time elapsed (sec.)	Intensity or strength (percent of peak value)	Time elapsed (sec.)
0	0.0	20	0.7
20	0.1	15	0.8
40	0.2	10	0.9
80	0.3	8	1.0
50	0.4	5	2.0
30	0.5	3	3.0
25	0.6	2	4.0

A somewhat different situation, in which the student is expected to make an inference on the basis of his knowledge of magnetic principles and of the general constitution of the atmosphere of the sun, is the following one:

Accurate measurements of the total number of sun spots and of the magnetic field of the earth have been made over a period of years. These observations indicate that the disturbances of the earth's magnetic field take place at the time of increased sun spot activity. Also, it is highly probable that the sun is a mass of gaseous material which is in an ionized state. From this information, what can you infer concerning the motion of the sun's atmosphere near a sun spot?

The student is expected to write out the most reasonable inferences which occur to him about the motion of the sun's atmosphere, on the basis of the foregoing information and his own information concerning the production of magnetic fields.

Another situation in which the student is expected to make an inference is given in the following example:

A person sitting near a radio and at the same time observing a distant electrical storm, notices that the crashing noise occurs at the instant the lightning is observed.

The students who have developed the ability to draw inferences will recognize from this information that the speed of light is approximately the

same as the speed of the disturbance which produces the crashing noise in the radio.

Application of principles. Another objective of the course in physics and astronomy is the development in the student of the ability to apply facts and principles to new situations. According to this objective, the student is expected to use facts and principles in order to make a prediction and then to give the reasons for his prediction in terms of the facts and principles. One typical application of principles to new situations is the following:

> An automobile is moving along a slippery road when the rear wheels suddenly begin to skid toward the side of the road. What can the driver do in order to right the car? Give the reasons which explain your solution.

The student is expected to apply the principle of centrifugal force and indicate the direction in which the wheels should be turned, and then to give the reason, or reasons, for the prediction which he has made.

An example in which the student is expected to apply certain principles obtained from the study of heat is the following:

> What change takes place in the weight of a piece of meat which is placed uncovered in a mechanical refrigerator? Give the reasons which explain what occurs.

Recognition of assumptions. Another objective which these instructors set up for their course is the development in the student of the ability to recognize the assumptions that underlie conclusions made from evidence of various kinds. The student, when given a conclusion which he or someone else has made from some kind of evidence, is expected to recognize those factors which must be taken for granted in order to accept the conclusion. For example, the following information was given to a class:

> In Oxford University only 10 percent of the students study music, yet this small group of musicians takes 75 percent of the scholarships and prizes for high grades. One student made the following conclusion from this information: "Of all subjects, music is the best mind-trainer."

The class was then asked to indicate the factors that had to be taken for granted in order to accept the conclusion. Similar types of examples may be taken from all phases of physical science to illustrate the importance of assumptions which are implicit in conclusions based on insufficient evidence.

Development of skills. One of the objectives of laboratory instruction in this course is the development of skills and technics. Criterions for the measurement of student achievement in this objective are obtained by observing the technics of students. The things the students do and the results they obtain in the laboratory may be observed, and recorded in the form of a check list. Then, to evaluate the achievement of a student in a particular technic, the instructor observes him in an actual experiment where the technic is required, and indicates on a check list those things which he does correctly as well as those which are incorrectly performed. For example, when connecting an electrical circuit which contains a voltmeter, an ammeter, and resistance elements, a student may begin by making connections at the source of power, he may not use the most appropriate range of the voltmeter, he may have the voltmeter and ammeter interchanged; and many other parts of his technic may or may not be good. These incorrect phases of the technic may be detected by means of this procedure and remedial instruction given.

Sensitivity to social implications of the physical sciences. The instructors in the unified course in physics and astronomy were also concerned with developing in students a sensitivity to the social and economic situations which are directly or indirectly due to discoveries in physical science. Achievement in this objective was construed to mean that a student be able to recognize the relation between the social or economic situation and the physical science discovery, or discoveries, which have been partly responsible for the situation. For example, the student should recognize that the developments of the steam engine, the electric motor, etc., have played a very important role in the development of the need for a six-hour working day.

Advantages of an adequate evaluation procedure

Several clear cut advantages result from a properly conceived and effectively administered evaluation procedure. Some of the more important advantages are:

Diagnosis of student difficulties. When the teacher singles out from the gamut of physical

science instruction those outcomes which he considers to be valuable and defines the kinds of activities of which the student's achievement should consist, specific test-situations may be given to the student which will lead to a diagnosis of his difficulties. For example, if the student experiences difficulty in recognizing generalizations which can be drawn from a set of data, this fact will be uncovered by the analysis of the student's written response when he is asked to recognize the generalizations. Or, if he is unable to identify the assumptions which must be accepted in order to accept a conclusion, this difficulty, too, may be uncovered by means of several test-situations in which he is asked to recognize those assumptions. The possibility of diagnosis of faulty technic in the laboratory has already been indicated.

Understanding of objectives by students. Another distinct advantage of such a system of evaluation is the effect on the student. Most teachers have experienced the question "What will we be held responsible for?" which is so often raised by students. Through the daily use of situations in class and laboratory which have come from the teacher's objectives, the student is able to obtain a much better idea of the achievement expected of him. In those objectives that involve some phase of thinking, the situations used to measure achievement should be new to the student in order to remove the possibility of a simple hand-back of a "pat" solution. It is also possible to include in specific test items, especially of the objective type, many different kinds of pitfalls which the student might not otherwise encounter. These pitfalls will be characteristic errors made by other students, and when these mistakes are included in tests, the reaction of the student will indicate whether he has any tendency to accept such errors.

Effect on the teacher. In any such system of adequate evaluation of student performance the effect on the teacher must not be overlooked. When the teacher is forced to ask himself just what it is that he is trying to do with students, what the changes are that he is attempting to bring about, then he is forced to make a thorough inventory of his instruction. In raising these questions, the teacher usually finds that he is forced to get an entire perspective of those objectives which he considers to be of value. Usually this type of inventory results in the recognition that a considerable portion of the instruction as it has been given can be modified to include some activities which will be of greater value to the student. Only by trial can the instructor decide whether it is possible to have students do certain things. It is easy for him to believe that many desirable outcomes have been attained. By means of the method of evaluation described here, it is possible for him to determine whether or not certain outcomes are brought about.

Source of specific information for others. One of the real limitations in education is the lack of specific information which can be handed along from teacher to teacher about the performance of different students. It is customary for instructors to begin instruction in a course without very specific information concerning the abilities of the students. At the beginning all receive the same instruction. Some time during the course, depending largely upon the instructor, individual differences become evident, and it is possible for the teacher to present more challenging activities to the better students. An evaluation procedure which places this information in the hands of an instructor at the beginning of the course allows him to attack the problem of individual differences from the start. A similar situation arises when teachers are requested to recommend their students. Rarely do they have worthwhile specific information to give to their colleagues or to others who ask for it. When adequate evaluation procedures have been developed, more significant information of the type desired can be supplied and the teacher can specify with some certainty what a student has done and what he may be expected to do successfully. The importance of such information for educational and vocational guidance is evident.

Experiments with a Unipolar Generator and Motor

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When Faraday made his discoveries in electromagnetic induction he performed a large number of experiments, one series of which is generally overlooked in any elementary discussion of the subject. These experiments were performed on December 26, 1831, and are described in his *Diary* as follows:[1]

"255. A copper disc was cemented on the top of a cylinder magnet [Fig. 1], paper intervening, the top being the marked pole; the magnet supported so as to rotate by means of a string, and the wires of the galvanometer connected with the edge and the axis of the copper plate. When the magnet and disc together rotated *unscrew* the marked end of the needle went *west*. When the magnet and disc rotated *screw* the marked end of the needle went *east*.

"256. This direction is the *same* as that which would have resulted if the copper had moved and the magnet been still. Hence moving the magnet causes no difference provided the copper moves. A rotating and a stationary magnet cause the same effect.

"257. The disc was then loosed from the magnet and held still whilst the magnet itself was revolved; but now no effect upon the galvanometer. Hence it appears that, of the metal circuit in which the current is to be formed, different parts must move with different angular velocities. If with the same, no current is produced, i.e. when both parts are external to the magnet."

The rule that an e.m.f. is created when lines of magnetic force are cut by a moving conductor gives an erroneous interpretation of these experiments. Another interpretation is that the e.m.f. generated in the rotating disk is fundamentally due to the Lorentz force on the electrons in the moving conductor placed in a magnetic field. The electrons move with the velocity $\mathbf{v}$ of the conductor and in the presence of a magnetic field $\mathbf{B}$ are acted on by a force $-e\cdot\mathbf{v}\times\mathbf{B}$ at right angles to both $\mathbf{v}$ and $\mathbf{B}$. Thus in Fig. 1, the electrons are moved to the rim of the disk and an e.m.f. is generated between the rim and axis of the disk. A comprehensive treatment of this subject, with many references to original articles, appears in a bulletin of the National Research Council.[2] The e.m.f. generated in the moving disk is conveniently referred to as a *motional* e.m.f. This subject is discussed in some detail by Page and Adams,[3] who suggest that rather than attempt to formulate the results of the experiments on induced electromotive forces in a single law it would be much better to regard induced e.m.f.'s as due to two distinct causes:

(a) "If the magnetic flux through any closed curve in the observer's reference frame changes with time, this change must be accompanied by an electric field of such a character that the electromotive force around the closed curve is equal to the time rate of decrease of magnetic flux through any surface bounded by the curve."

(b) "[A *motional* electromotive force] is found when a conducting wire is put into motion relative to the observer's inertial system. Then, if a magnetic field $\mathbf{B}$ is present, an electromotive force is produced along the wire of magnitude $\int \mathbf{v}\times\mathbf{B}\cdot d\mathbf{l}$ where $d\mathbf{l}$ is an element of length of the conductor and $\mathbf{v}$ its velocity."

An apparatus has been constructed similar to that of Faraday's so that by a few comparatively simple changes it is possible to have the magnet and disk rotate together, the magnet rotate and the disk remain at rest, or the disk rotate while the magnet remains at rest (Fig. 2). With it one may easily verify Faraday's results and also show that reversing the magnet reverses the direction of the e.m.f. and that the magnitude of the e.m.f. increases with increase in angular

[1] *Diary* (Bell, 1932), p. 402.

[2] *Electrodynamics of Moving Media*, Vol. 4 (1922), Pt. 6, p. 85.

[3] Am. Phys. Teacher **3**, 56 (1935).

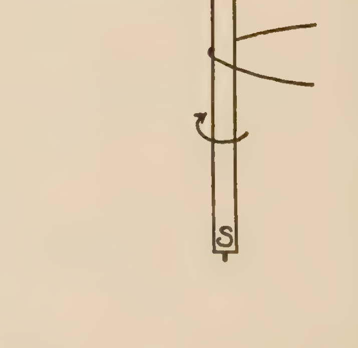

Fig. 1. Faraday's experiment.

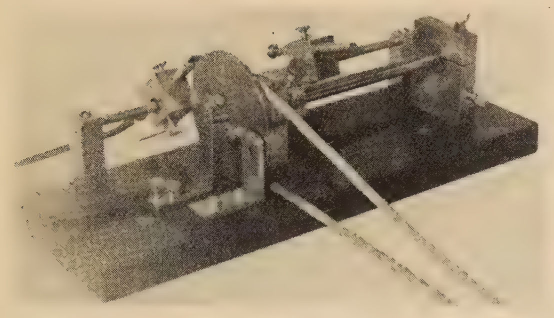

FIG. 2. Unipolar generator.

speed of the disk. It also follows that if the leads as well as the disk rotate about the axis of the magnet the resultant e.m.f. and current are zero. Furthermore terminals are provided so that contacts may be made either at two different points long the edge of the magnet or between the side and axis of the magnet. The maximum e.m.f. is obtained when one contact is made at the edge of the magnet at its mid-point and the other is at the axis of the magnet. When the contact on the edge is moved from the middle towards one end the e.m.f. is reduced because at its end the flux inside the magnet is less than at its middle. All these experiments are successfully interpreted by using the idea of motional e.m.f. This apparatus is often referred to as a *unipolar generator*. It produces a direct current without the use of the usual commutator brushes.

Fig. 3 shows a *unipolar motor*. In this case a current sent through a magnet produces rotation whereas in the unipolar generator rotating the magnet produces a current. The apparatus is constructed so that a current may be introduced along the axis of the magnet and leave the magnet at some point where there is an arm and a mercury cup. The force *Bil* on this arm carrying the current is such as to tend to produce clockwise rotation, looking down on the apparatus. However, it is found that the magnet rotates in the opposite direction; that is, counterclockwise (Fig. 4a). This is because there is also a torque due to the current and the flux *inside* the magnet; the current entering the arm must pass out of the magnet at right angles to the flux inside the magnet. The flux inside is in the opposite direction to that outside; hence the two torques, that on the arm and that on the magnet itself, are in opposite directions. The magnitudes of

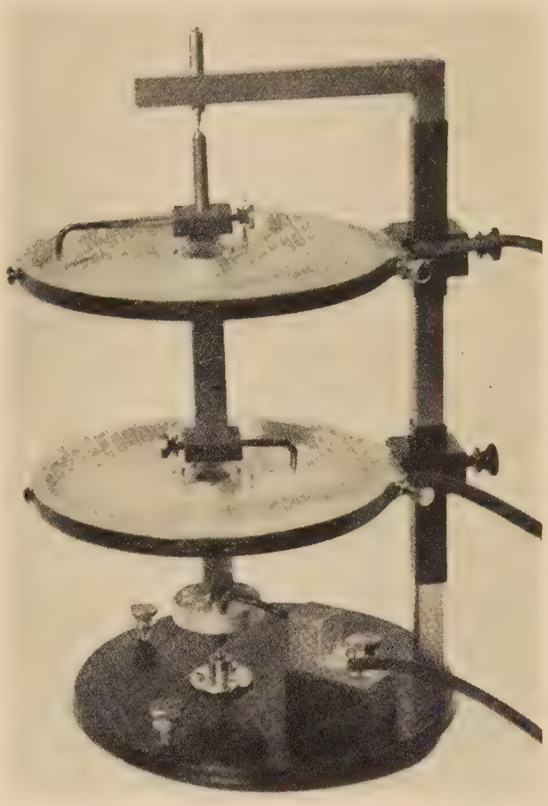

FIG. 3. Unipolar motor.

these torques are given by the expression $I\phi/2\pi$ where I is the current and ϕ is the flux.[4] The flux inside the magnet is greater than that over the arm. Hence the counterclockwise torque is greater than the clockwise torque. That this is so is shown by the fact that the magnet rotates with a greater speed when a

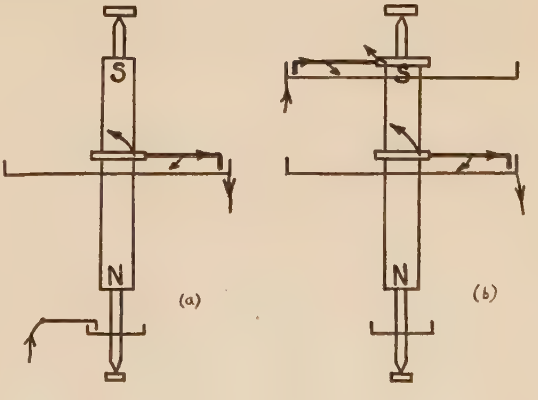

FIG. 4. Motion of unipolar motor.

[4] Page and Adams, *Principles of Electricity*, p. 315.

shorter arm is used. This experiment also shows that it is BA, the magnetic flux, which is involved in the torques rather than HA, the product of the magnetic field and area. The flux density **B** inside a permanent magnet is in the opposite direction to the field **H**. Were this latter quantity used the two torques would be in the same direction and the magnet would rotate in a clockwise direction.

The current may be introduced at the midpoint of the magnet and leave at the top through a similar mercury cup. In this case four torques are produced but the torque on the magnet at the top is smaller than at the middle since the flux inside the magnet at the top is smaller than at the middle. Hence there is a resultant torque and rotation is produced (Fig. 4b). With this apparatus, as with the previous one, a qualitative measure of the flux within a magnet may be made. This latter apparatus emphasizes the fact that magnetic lines of flux are continuous and exist within a permanent magnet as well as outside of it. It may be mentioned that unless good bearings and a strong magnet are used the torque is not sufficient to produce rotation. With "jewel" bearings and a cobalt-steel magnet it was found that a single new dry cell provided sufficient current to produce rotation.

Some Elementary Laboratory Experiments in Mechanics and Electricity

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LAST summer we revised certain of our elementary courses and it is possible that some of the developments made at that time may interest other teachers. The present article contains some material selected from courses in mechanics and electricity taught both with and without calculus. An article to follow will deal with similar ideas for courses in heat and optics. No systematic attempt has been made to search the literature for descriptions of these experiments, and we apologize in advance for any plagiarisms which we may have committed.

The Behr free-fall experiment

The Behr free-fall experiment is probably the most widely-discussed experiment performed in any elementary laboratory. We will not describe it except to remind the reader that a metal weight falls freely between two vertical wires, and that a high voltage spark jumps every thirtieth of a second between the wires thus leaving a record, on a paraffin-coated paper strip, of the progress of the weight. The weight is suspended at the top from an electromagnet, and the time of its release, caused by opening a switch, does not in general coincide with any one of the sparks. Hence, when the next ensuing spark jumps, the weight already has a certain "initial" displacement from the zero position, and a certain "initial" speed. We find that this situation causes considerable confusion among the students. Those who take the course without calculus seem to be unable to understand the significance of the intercepts on the graphs by means of which they analyze their data. For the engineering students one likes to use an analytic method of reducing the data, and of course the method of least squares is the only correct way of doing this. But unfortunately this method is pretty complicated in the present case. Our remedy for the situation, suggested by Mr. D. G. C. Hare, is to put an extra contactor on the synchronous motor and use a relay and push button connected with a suitable circuit so that

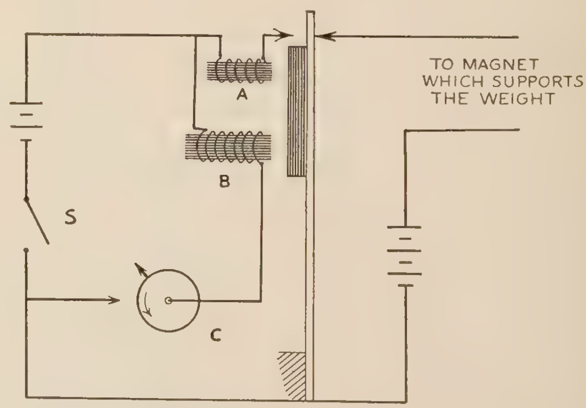

Fig. 1. Wiring diagram for free-fall apparatus.

depressing the button causes the magnet to release the weight at the instant of the next following spark (Fig. 1). The contact which controls the magnet stays open until the push button S is released. The extra contactor can be rotated about the axis of the motor so as to enable the instructor to adjust the synchronization of the release with the spark. This is done by working backwards after computing where one of the sparks *should* appear on the paper strip.

For the engineers, it might seem that this would take all the fun out of the method of least squares, but this is by no means the case. The experiment is inherently capable of great accuracy and, in order to capitalize on this, one must still take the initial *speed* into account in the formulas. This initial speed arises from the residual error in the timing of the relay. The initial displacement is only a minute fraction of a millimeter, and may be neglected, with the result that the least-squares formulas are now simple enough for the student to derive and understand them, after reading a general discussion of the method. We give this general discussion in our laboratory manual, and from it the student verifies that the acceleration g is given in terms of the distances S_n by

$$\sum_{n=1}^{N} S_n(n^2A - nB) = (gT^2/2)(CA - B),$$

where T is the time interval between sparks, and

$$A = \sum_{1}^{N} n^2 = (2N^3 + 3N^2 + N)/6,$$

$$B = \sum_{1}^{N} n^3 = (n^4 + 2N^3 + N^2)/4,$$

$$C = \sum_{1}^{N} n^4 = (6N^5 + 15N^4 + 10N^3 - N)/30.$$

If N is a large number (about 20 in our experiment) it is perhaps worthwhile to give the students a short table of the numerical values of A, B, and C.

Friction

Our experiment on friction is almost unique—it gives reproducible results! To accomplish this it is merely necessary to use smooth reproducible surfaces. For one surface we use plate glass which is as smooth and flat as could be desired and which can be cleaned chemically with chromic acid. This glass is flooded with a layer of oleic acid which is a single chemical compound and therefore reproducible. Moreover, oleic acid has a strong tendency to stick to the glass. The slider which rests on the glass-oleic acid surface is a triangular piece of brass with three ball bearings soldered to the corners. The three balls press through any large-scale film of oil and rest on the monomolecular layer of oleic acid, and their diameter is so small that the viscous friction can be neglected.

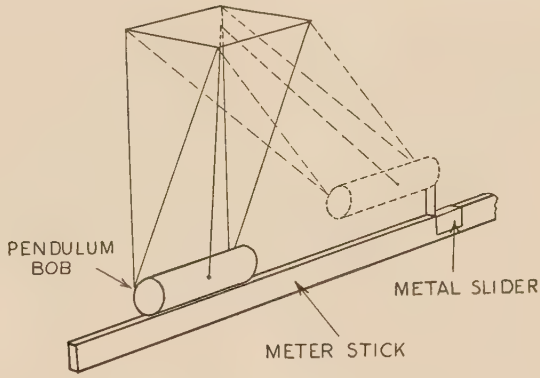

FIG. 2. Diagram of ballistic pendulum.

The second part of the same exercise is another friction experiment that likewise works. A steel-disk flywheel is attached to a 1/4-h.p. induction motor. On one face of the disk is painted a stroboscopic pattern as follows. The disk is divided into a number of concentric rings. In each ring is placed a certain number N of spots of black paint, spaced at equal intervals around the ring. The pattern is illuminated with a neon lamp arranged to flicker 60 times per second, and the spots in a given ring will appear to be standing still if the disk is rotating $60/N$ times per second. The innermost ring contains two spots and corresponds to 30 rev./sec.; since this is very nearly the speed of the motor when the current is on, one will see this pattern almost standing still. The motor is then turned off and the time recorded. This pattern will gradually disappear and one watches for a pattern to appear in the next ring. One records the exact time when this pattern becomes stationary, and then watches the third ring, etc. In this way various assorted rotational speeds down to

2 rev./sec. are "timed." From the resulting graphs of angular speed and acceleration *vs.* time, and a computation of the moment of inertia of the flywheel (neglecting that of the armature), a graph is made of total frictional torque as a function of rotational speed. The results are accurately reproducible, and we believe that this study of friction in a place where it actually occurs in electrical engineering practice, is good pedagogically.

The ballistic pendulum

Many methods of suspending a ballistic pendulum have been suggested, but none of the ones previously known to us satisfies the following three requirements: it must be nearly frictionless; the pendulum must have just one degree of freedom; the motion must be one of translation only, unless one is willing to take rotational kinetic energy into account in the formulas. The common four-wire suspension fails to satisfy the second requirement. A rigid body has six degrees of freedom, and to eliminate all but one, five constraints are needed. These can be introduced by means of *five* suspension wires arranged as shown in Fig. 2. This system works very satisfactorily and its virtues are immediately obvious to the student when he takes the bob in his hand and moves it back and forth. In computing the height of rise h, it is found instructive to have the student expand in power series the expression $h=R-(R^2-d^2)^{\frac{1}{2}}$, where R is the length of the pendulum and d is the distance moved by the metal slider.

It might also be mentioned that this experiment as frequently performed constitutes merely a measurement of the speed of the object (e.g. a rifle bullet) which strikes the pendulum, assuming that the law of conservation of momentum is correct, and actually proves nothing. Obviously one must have an independent means of measuring the speed in order to verify the conservation law. The independent method we have adopted is to have two cardboard disks mounted on a long axle connected to a synchronous motor and to fire the bullet parallel to the axle and through the two disks while they are rotating at 1800 rev./min. A second shot is then fired with the disks stationary. The rest is obvious. After the measurement is finished the student pastes pieces of sticky brown paper tape (such as is used in wrapping packages) over the holes so that the disks can be used again by other students.

Electrostatics

We have an electrostatics experiment, inherited from Professor Emeritus F. J. Rogers, that works every day, is quantitative, and really shows something. The apparatus consists of a Braun electrostatic voltmeter with a cylinder (Faraday cage) supported from the insulated terminal, a gold leaf electroscope, and the piece of homemade apparatus illustrated in Fig. 3. Before the handle is used it is cleaned with sandpaper and discharged by passing it quickly through a Bunsen flame.

The student is directed to charge the "paddle" by touching it with a flexible wire from the d.c. line. With this method the paddle is always given the same amount of charge. He then touches the outside of the Faraday cage with the paddle, removes the paddle and tests it for charge with the gold leaf electroscope. By repeating this test after touching the inside of the Faraday cage he becomes convinced that if he touches the inside, *all* the charge will be transferred to the Braun voltmeter. The student then transfers 5, 10, 15, and 20 "paddlefuls" of charge to the Braun voltmeter and reads the voltages. In this way he verifies that, for a system of fixed capacitance C, the voltage V is proportional to the charge Q. Next he repeats the experiment with a paddle of twice the area. This will show the effect of keeping V constant and changing C. Then a grounded plate is put near the Faraday cage, thus increasing the capacitance of the Braun voltmeter system, and the experiment is repeated to show the effect of changing C with Q kept constant. Various quantities, such as the capacitance of the Braun voltmeter and associated Faraday cage, are then calculated from the data.

Just about the time the student thinks he knows all about the experiment, he is instructed to charge the voltmeter two or three times, now using waxed paper or thin mica as a spacer for the paddle instead of the hard rubber buttons shown in Fig. 3. The capacitance of the paddle with respect to the plate now may be 10 or

more times that of the voltmeter; hence the voltmeter may increase its reading by 1000 v or more on receiving the charge on a paddle that originally was charged to a potential of 110 v. This never fails to astonish the students and, by the time they figure it out, they can hardly avoid acquiring some understanding of potential.

E.m.f. and potential difference

In this experiment one measures the potential difference of a cell as a function of current. If the experiment is to work well the cell must have a constant e.m.f. and constant internal resistance. It is desirable that this resistance be large enough so that load resistances which are less than the cell resistance can be used conveniently. Excellent for this purpose are Daniell cells in ordinary drinking glasses and with small flower pots to separate the solutions. They have a constant e.m.f. of 1.097 v, do not polarize, and have a constant resistance of about 10 ohms. The information obtained in the experiment is so important and can be related to so many things that it is worthwhile to have the student use one set of data to plot several graphs, as follows. A plot of potential difference as a function of current I is made, and extrapolated to find the e.m.f. As an exercise in the graphical reduction of data, $1/I$ is plotted against external resistance R; one intercept of the resulting straight line gives the cell resistance. As an introduction to the important connection between impedance matching and power transfer, the power generated in the cell, the power lost in the cell and the power transferred to the external circuit are plotted as functions of I and also of R.

Alternating currents

In the teaching of alternating currents to beginners we have found it better to begin with condensers instead of inductances. An inexpensive capacitance of about 20 μf can be built up from filter condensers such as are used in

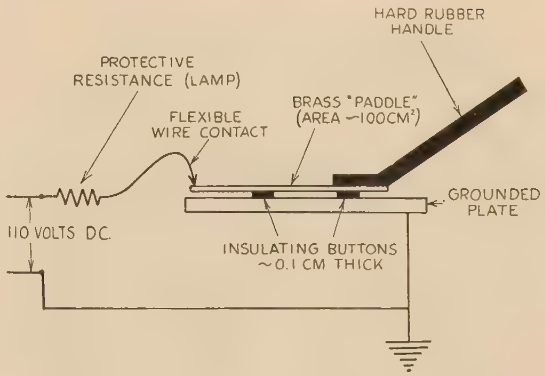

FIG. 3. Device for charging the "paddle."

radio sets and will pass about 1 amp. at 110 v. The condensers have a low power factor and do not change value with current as iron core inductances often do. Thus the student does not have to waste his time finding alibis as to why the simple formulas do not work out quite right. Of course, inductances are used also and we have been careful to increase their L/R ratio as much as possible and at the same time have an ample air gap to avoid saturation effects. The experiments used involve little that is original though there may be some interest in the following two.

1. A variable resistance and a condenser are connected in series. A wattmeter measures the total power; the current and various voltages are also measured. On varying the resistance from zero toward infinity the power rises from zero to a maximum and then decreases toward zero. This interests the student, affords a good calculus problem on maxima and provides an opportunity to study power factor.

2. This experiment, on series resonance, involves a 20-μf condenser and an inductance to match at 60 cycles. The unique feature is the use of an electrostatic voltmeter for the measurement of the voltages. Large errors due to currents drawn by the voltmeter thus are avoided and a fairly good check of the theoretical voltage-multiplication is made possible. The electrostatic voltmeters were made in the shop and are simply crude electrometers with galvanometer ribbon-suspensions. They are more rugged than a galvanometer because they use the same suspension but have a much lighter moving system. It seems likely that high resistance rectifier-type voltmeters would also work well.

Truth comes out of error more easily than out of confusion.—FRANCIS BACON

Illustrations in Elementary Textbooks

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The development of survey courses in the physical sciences has created a demand for new types of physics books which are less formal and less mathematical, though not necessarily more elementary, than the first-year college texts of a decade or two ago. A device which is now used successfully to stimulate student interest and add zest to study is the frequent embellishment of the pages or the margins with drawings which are humorous or facetious, or which draw on athletics or other forms of student activity for examples of physical principles. Illustrations of more than incidental importance represent devices of practical engineering significance rather than apparatus that is found only in laboratories.

That it would be wrong to describe these trends as innovations is clear from a book which has lately come to my notice, entitled *Philosophy in Sport made Science in Earnest*, by John Ayrton Paris. The first edition of this work appeared anonymously in England in 1827, with a dedication to Miss Maria Edgeworth, couched in part as follows:

> "To whom can a work, which professes to blend amusement with instruction, be dedicated with so much propriety, as to one, whose numerous writings have satisfactorily demonstrated the practicability and value of such a union."

The illustrations are wood engravings from designs by George Cruikshank, and indeed several of the finer ones appear to have been executed by Cruikshank himself, since the initials *G. C.* are to be found on a tree-trunk or elsewhere in most of the figures which have been selected for reproduction in the present paper. Although he was a prolific caricaturist and illustrator of novels and topical books, it appears

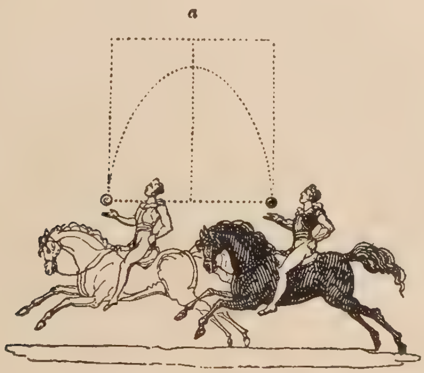
that Cruikshank illustrated only one other scientific work,[1] Pettigrew's *Egyptian Mummies*.

Doctor Paris' book, *Philosophy in Sport made Science in Earnest*, originally composed for the exclusive use of his children, recounts the quiet adventures of a certain Seymour family in a small English village. The course of the story is guided by a promise, made by Mr. Seymour, of furnishing his son with some new amusements during the holi-

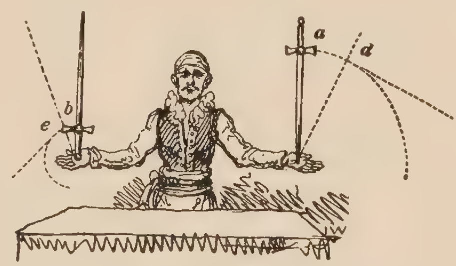
[1] The writer is indebted to Professor E. C. Watson for this observation and for other suggestions relating to the manuscript.

days, a fact which the boy was not slow to recall upon his return from boarding school.

> "I perfectly remember [said his father] the promise to which you allude, and I hope that you equally well recollect the conditions with which it was coupled. When your mamma gave you a copy of Mrs. Marcet's instructive Dialogues on Natural Philosophy, I told you that, after you had studied the principles which that work so admirably explains, you would have but little difficulty in understanding the philosophy of toys, or the manner in which each produced its amusing effects; and that, when the midsummer holidays commenced, I would successively supply you with a new amusement, whenever you could satisfactorily explain the principles of those you already possessed."



The scene at the well-head depicts the experiment of finding the depth of a well by dropping a pebble into it. Mr. Twaddleton, the vicar, stands by with his watch to note the time, while the village spinster peers from behind a tree wondering what mischief is afoot. It is easy to assign to all but one of the remaining pictures the physical principles which they are designed to illustrate—the oscillations of a pendulum, the laws of momentum in the game of marbles, the parabolic path of a flying ball, Newton's third law of motion, and the importance of the height of the center of gravity in a problem of unstable equilibrium. The remaining picture shows Mr. Twaddleton standing aghast at an apparition which approaches in a cloud of dust and smoke. It is Dr. Doseall's steam carriage, to



which that ingenious gentleman had attached machinery for boiling medicines and grinding powder for pills. The story relates how it exploded, fortunately without serious hurt to the doctor and while the vicar was still out of the danger zone.

Doctor Paris was a successful physician, and the author of many books on medical subjects. During his last illness, in 1856, he corrected proofs of the eighth edition of his *Philosophy in Sport made Science in Earnest.* A good account of his life appears in the *Dictionary of National Biography.*

The Partition Between Physical Object and Observer[1]

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THE interpretation of a physical description presupposes that an imaginary boundary has been drawn between the object of observation and the describing observer. In view of the recognition in non-relativistic quantum mechanics of an uncontrollable disturbance of the object by the apparatus employed by the observer, the position of the partition has become of interest in physics. Now, there is a lack of clarity in current discussion on account of the failure to distinguish carefully between the functions of measuring instruments and perceiving organisms. In the present paper I shall analyze the relations between the physical interaction of object and instrument and the supervening process of perception.

I

As a foundation for the discussion I shall explain the concepts of *physical object* and *observer*. A physical object may be exemplified by a perceptible material body, such as an approximately rigid, iron rod. Now the proposal to analyze the concept of object appears to invite a philosophical debate. In accordance with a previously published analysis,[2] however, I present a theory which is formulated so generally that it should be acceptable to all theorists of scientific methodology. In the inductive development of physical theory, primary objects are perceptible solid and fluid bodies. Such physical objects are initially centers of reference for experiences. In other words, a primary object of physical theory is an entity of which aspects may be given in experience. An *aspect* is an immediate datum of experience, for example, the visual aspect of a billiard ball. Originally, the aspects of primary physical objects are given vividly in perception, but experience also involves the remembrance and anticipation of correlated aspects of an object. A general theory of objects may now be expressed in two principles. The first principle is that some physical objects exist to which correlated sets of aspects belong that may be given in perception. The second principle is that the structure of objects is manifested in the structure of their perceptible aspects. This latter principle is sharpened in metrical physics to the statement that the space-time coincidence of perceptions signifies the space-time coincidence of the properties perceived. Thus the contact of two bodies at a given time is exhibited in the contact of their perceptible aspects. The concept of contact becomes precise only if bodies are idealized as particles, that is, material points. Through observed correlations between properties an observation of one property may serve as an indirect observation of another. In order to maintain the generality of application of physical laws, objects that are not directly perceptible are assumed, such as molecules, atoms, and the several elementary particles of microscopic physics. For the description of the behavior of physical objects there have been fashioned the concepts which are defined by the principles of classical physics. In classical theories physical quantities are ascribed to objects independently of the context of observation; that is, there is employed an absolutistic conception of reality. The foregoing exposition recognizes that the function of physical objects is to serve as instruments of prediction and control of perceptions. This instrumentalistic theory is embodied in the quantum mechanical conception of the state of a microphysical system as an instrument of statistical prediction of the results of observation. In classical physics the objects are instruments of certain predictions of perceptions; in quantum mechanics only probabilities of observation are in general predictable.

The observer I shall view behavioristically. The nucleus of the observer is the perceiving organism, which is one of the bodies in the physical world. I use the term nucleus, because the organism is extended by radiation and measuring instruments which may be included

[1] Based upon a paper read before the Second International Congress for the Unity of Science, Copenhagen, June 21–26, 1936.

[2] Nature **136**, 433 (1935). Compare with the writer's article, "The Philosophical Problem of the Existence of the Physical World," Am. Phys. Teacher **2**, 152 (1934).

as part of the observer. As emphasized by Bohr, the observer and his instruments must be presupposed in any investigation, so that the instruments are not described but used. In order to describe the process of observation it is necessary, therefore, to adopt the behavioristic standpoint of an outside observer, as set forth, for example, by E. C. Tolman.[3] A typical observation is touch. If a tactual experience occurs, an outside observer describes the process as an interaction between a physical thing and some part of an organism, such as the tip of a finger.

II

Observation involves the interaction of an object and an observer. It is clear that the description of the interaction depends upon where we draw the line between object and observer. A cardinal principle of contemporary physical theory is that *the place of the partition between object and observer may be assigned arbitrarily*. In order to explain this principle I shall draw upon the detailed analysis which has been made by J. von Neumann.[4] The following is a selection:

"A temperature is measured. If we wish we can trace this process in calculation until we have the temperature of the environment of the bulb of the thermometer, and then say: this temperature is measured by the thermometer. We may, however, extend the calculation and from the molecular-kinetic properties of mercury calculate its heating, expansion, and the resulting length of the mercury thread, and then say: this length is seen by the observer. Still further, taking into account his light source, we could ascertain the reflection of the light quanta at the opaque mercury thread and the path of the remaining light quanta into his eye, then their refraction in the lens and production of a picture upon the retina, and only then would we say: this picture is registered by the retina of the observer. And if our physiological knowledge were more accurate to-day, we could go still further, tracing the chemical reactions which this picture on the retina produces in the nerve fiber and in the brain, and only at the end say: these chemical changes of his brain are apperceived by the observer. But no matter how far we calculate; up to the mercury bulb, up to the scale of the thermometer, up to the retina, or into the brain, sometime we must say; and this is perceived by the observer. That is, we must always divide the world into two parts, the one is the observed system, the other the observer. In the first we can trace all physical processes (at least in principle) as accurately as we wish; in the latter this is meaningless. The partition between the two is to a considerable extent arbitrary; thus we saw in the above example, four different possibilities for it. In particular, the observer in this sense is in no way to be identified with the body of the actual observer; in our above example we once even viewed the thermometer as belonging to him, while on another occasion his eyes and nerve fibers were not ascribed to him."

In development of the theory of the partition I analyze a complete observation into physical registration, stimulation, and perception. Accordingly, I distinguish between the *physical*, *biological*, and *perceptual* partitions. In the preceding example a thread of mercury in a thermometer is seen by an observer when measuring a temperature, but the object of measurement is the temperature of the environment. The environment registers an effect upon the thermometer and so the physical partition is between environment and thermometer. Light reflected from the thermometer stimulates the retina, and one would ordinarily place the biological partition between the light and the retina. The observer perceives the thermometer as distant from him; accordingly, the perceptual partition is placed between the thermometer and the light with which it is seen.

III

The theory of the partition enables one to solve the problem of the locus and time of the perceptible aspects of an object. In adaptation of a theory of Ernst Mach I shall consider an aspect to be mental if viewed as functionally related to the observer, to be physical if considered as functionally related to things external to the observer.

As physical, an aspect must have position in space and time. The visual aspects of an object depend upon radiation which is reflected from the object to the observer; hence a visual aspect is the joint product of radiation and object. On account of the finite speed of propagation of radiation, the state to which a visual aspect belongs is prior to, and distant from, the perception of the aspect. This transcendence of the object of perception has been repugnant to common sense. The opposition between the scientific recognition of transcendence of the object and the demands of common sense can be reconciled by the convention that the place of the aspect is that of the partition between object and observer, and the

[3] *Purposive Behavior* (New York, 1932).

[4] *Mathematische Grundlagen der Quantenmechanik* (Berlin, 1932).

time is that of the interaction. For example, suppose that one is looking at a stick and that the atmosphere is clear. The visual aspect of the stick is dependent on sunlight which is reflected from the stick to the eye. In daily life the thing of interest is the stick; the light is an instrument of observation which may be viewed as an integral part of the observer. The perceptual partition between object and observer is between the stick and the light; that is, the partition is at the stick, and accordingly one locates the visual aspect at the stick. As a physicist one may view the visual aspect as the product of radiation and stick, and therefore locate the aspect at the place of interaction in accordance with the principle of contiguous causality. In observing, however, the dependence of the visual aspect on the medium between the stick and the eye, one is led to view the aspect as resulting from the action of the light upon the retina. The physical partition is now placed between the light from the stick and the retina of the observer, and so the visual aspect is located at the retina. In this example the physical partition is different from the perceptual partition. The latter is ordinarily at the perceived object which is distant from the observer. As E. Brunswik[5] has shown, however, a change in perceptual attitude is possible; for example, we can compare things with respect to the size of the pattern on the retina produced by the light from them. In such an example we are to think of the perceptual partition as at the retina.

Bohr has cited an example from touch. Let us suppose that one firmly grasps a long stick in one's hand and touches a body with the end of the stick. The body is the object of observation; the stick is an apparatus which is considered to be a part of the observer. The perceptual partition is between the body and the end of the stick; it accords with psychological fact that we locate the tactual aspect at the end of the stick. If, however, the stick is held loosely in the hand, the stick is considered as belonging to the object of observation; the partition is between stick and hand, and the surface of contact between them is the place of the tactual aspect.

It is ordinarily difficult to displace the perceptual partition, but the physical partition can be displaced arbitrarily. Accordingly, progress in science consists in displacing the physical partition in a twofold manner. The naive observer assumes that he is in direct contact with a distant object; indeed, the child reaches for the moon. But we have discovered that our visual perception of a distant object is dependent on radiation which produces its visual aspects. Physical investigation reveals that the radiation is affected by an intervening medium, and so the observer becomes limited to a definite organism which is separated from external things by a biological partition. The problem of the physicist ends when he reaches the surface of the perceiving organism. The biologist, however, displaces the partition into the body of the observer. Thus the optometrist places the partition at the retina of the eye; the physiologist of the nervous system displaces the partition still further into the organism. von Neumann suggests that ultimately we may place a partition between brain process and an abstract "I." It appears to me, however, that one should interpret the final term in perception as a mode of behavior.

While the biologist displaces the physical partition further and further into the organism, the physicist displaces the partition further and further into the physical object. In macroscopic physics he studies the surface properties of bodies; in microscopic physics he penetrates to the molecule, the atom, and now the nucleus. The perceptible effects of microphysical elements, which are not directly perceptible, serve as instruments of observation which thereby become incorporated in the observer. After long experience with the condensation tracks produced by electrons and other elementary particles one may come to view the perception of the tracks as a direct observation of the particles; that is, the perceptual partition has been so displaced that it coincides with the physical one. As we have seen, the physical partition may be displaced arbitrarily. It should be noted, however, that a displacement introduces a new object for physical description. Bohr has remarked that in practice the position of the partition is determined by the given experimental arrangement.

[5] *Wahrnehmung und Gegenstandswelt* (Leipzig u. Wien, 1934).

IV

The preceding reference to the observation of microphysical entities is now to be supplemented. The presupposition for observation of such entities is an acknowledgment of the existence of perceptible macrophysical bodies. Classical physics furnishes us with laws of behavior of such perceptible objects. These laws are expressed in terms of physical quantities; assuming a theory to be complete, its principles constitute an implicit definition of the fundamental quantities.

In microphysics, which adopts the concept of observation from classical physics, classical concepts are employed in the interpretation of phenomena. This procedure leads to the acknowledgment of the existence of microphysical entities as causes of the behavior of perceptible objects. For example, the irregular Brownian motion of small particles dispersed throughout a fluid is attributed to the impacts of molecules which interact with the particles in accordance with the principle of conservation of momentum. Similarly, the transfer of momentum and energy to a mirror by light provides a ground for the introduction of photons possessing momentum and energy. Thus we extend the world of perceptible objects by microphysical objects which interact with them. In this procedure we acknowledge that fundamental physical principles express functional relations which are constituents of reality like the physical properties of perceptible objects. Microphysical objects have as much or as little reality as the physical properties of the perceptible objects with which they interact. One must especially reject the view that the physical properties of perceptible objects are real and the microphysical objects are fictions. *Both kinds of object are physically real and have the same kind of ultimate reality.*

Now, although microphysical entities are to be acknowledged as physically real, the characterization of these entities in classical terms is limited in quantum mechanics. The applicability of a principle such as the conservation of momentum is relative to the experimental situation. For example, in an observation of position which is based upon the effect produced on a screen rigidly attached to the frame of reference, conservation of momentum is not applicable. Physical properties which were assumed in classical physics to be independent of observation are viewed in quantum mechanics as relative to an experimental situation. The dynamical properties assignable to microphysical entities are relative to the instruments of observation.

In order to analyze microphysical observation in detail one must distinguish between *physical registration* and *perception.* The object first registers an effect upon some instrument. The fundamental assumption for measurement is that specific properties of the effect are coupled with specific properties of the object, and to this extent classical causality is retained. For example, if an electron impinges on a screen, the effect, which may be idealized as a point, indicates the position of the point-electron during the registration. The momentum, however, is disturbed in an uncontrollable manner. The change in momentum cannot be determined from the momentum of the instrument, because in this example, the instrument is a screen which must be assumed to be rigidly attached to the frame of reference and therefore presupposed in the description of the phenomenon. In the initial stages of metrical physics the instrument must be a macrophysical object. When the properties of a microphysical object have been defined in terms of macrophysical instruments, it may also serve as an instrument. In being used as an instrument the microphysical entity must eventually register an effect upon a screen or other macrophysical instrument.

The second factor in observation is perception. The final term in physical measurement is the perception of space-time coincidence of two events. If the object has registered a relatively permanent effect on some screen on which coordinate lines have been drawn, perception may be postponed until a time after the object has acted on the instrument. The fundamental principle governing the final stage of measurement is that two coincident events are perceived as coincident. If one wishes to give a physical explanation of perception, one may imagine that two points in contact at a given moment scatter light of vanishingly small wave-length, which, in accordance with geometrical optics, produces two effects in contact on the retina. The coupling

between the contact of points on the retina and the perception of contact must be assumed to be an analogous process. Thus perception, which is the final term in measurement, is explained in terms of classical principles by an outside observer. The possibility of perception of coincidence is the basis of objectivity in physical measurement. Such objectivity is presupposed in quantum mechanics through the principle that the immediate repetition of an observation yields the same result. The perception of two coincident events is equivalent to two perceptions of one event in immediate succession.

V

The theory of observation of microphysical objects may be further explained by a discussion of an argument by Einstein, Podolsky, and Rosen[6] that the quantum mechanical description of physical reality is incomplete. In the following, numeral *I* will designate the object of observation, *II* the instrument of measurement, and *III* the perceiving organism. When used as an instrument *II* is considered to belong to the observer, and the physical partition is placed between *I* and *II*+*III*. In a theory of the measuring instrument one must view *II* as an element of the object and place the partition between *I*+*II* and *III*. As has been emphasized by Heisenberg,[7] the physical partition is the seat of an indeterminacy. In the interaction between object and instrument the object registers an effect on the instrument, which reacts to a finite extent in an uncontrollable manner upon those quantities of the object that are canonically conjugate to the quantity being measured. In the language of von Neumann, a pure state is transformed into a mixture. In order to express the foregoing statement in statistical terms let it be assumed that there is given an ensemble of systems, all of which are initially in the same state. If every one of the systems is subjected to an interaction with an instrument of measurement, the ensemble will become a mixture of sub-ensembles, each sub-ensemble consisting of the systems which are in an eigenstate belonging to a definite value of the quantity. For a single system one knows the probability that the physical quantity will be observed to have one of the possible values. The disturbance of the object in interaction with an instrument may also manifest itself in an unpredictable change of state with respect to the quantity being measured. Thus if the object is initially in a state of indeterminate position, a position-measurement forces it into an eigenstate belonging to a determinate value of position. This determinate value is coupled with the position of the effect on the measuring instrument. The perception of the record of the interaction then enables one to discover which value has been realized. The seat of objective indeterminacy is at the partition between object and instrument; perception as observation of the record merely removes subjective uncertainty regarding the outcome of physical registration.

As a foundation for their argument, EPR adopt the following criterion of physical reality: "If, without in any way disturbing a system, we can predict with certainty the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity." It follows from this criterion that if the state is such that one can predict with certainty the result of a momentum measurement, the momentum is real, but the position is then unpredictable and hence unreal. EPR present an example in which it is supposed that *I* and *II* interact and then cease to interact. They contend that one may then measure either the position or momentum of *II*, and infer the position or momentum of *I*, without affecting the system. Since the system has not been acted upon after the interaction, it appears that one must attribute reality simultaneously to two conjugate quantities. Since the wave function symbolizing the system does not enable one to predict both values simultaneously, it follows that the quantum mechanical description of physical reality is not complete.

My criticism of EPR is that, as Bohr[8] has pointed out, they have not sufficiently analyzed the conditions of measurement of a microphysical quantity. In order to measure position by means of a screen, the latter must be rigidly attached

[6] Phys. Rev. **47**, 777 (1935). Referred to hereafter as EPR.

[7] *Wandlungen in den Grundlagen der Naturwissenschaft* (Leipzig, 1935).

[8] Phys. Rev. **48**, 696 (1935).

to the frame of reference during the registration of the effect. This circumstance excludes the possibility of a later momentum measurement. In order to measure momentum by means of the screen, the latter must be mobile, but then position is lost. The wave packet which is reduced by observation depends on the experimental arrangement. Canonically conjugate quantities require mutually exclusive experimental procedures; and once the procedure is chosen, the appropriate representation by a wave packet is determined.

Now the essential element in the quantum mechanical theory of physical reality is that a physical property is relative to an experimental situation. As Schroedinger[9] has emphasized, the state of a system is an instrument for the statistical prediction of the values assumed by physical quantities in specific experiments. The EPR criterion of reality accords with this view in so far as the criterion may be expressed by the statement that physical reality is an instrument for the prediction, with certainty, of the results of observation. The application of this criterion to the position of a microphysical object yields the result that its position may be real only at the time of the interaction between object and instrument. But EPR also adopt the absolutistic conception that reality is independent of observation, for they assign position and momentum to an object after the observation. The incompleteness discovered by EPR results from the application of an instrumentalistic criterion of physical reality to an absolutistic, instead of to a relativistic conception of physical properties. But as Bohr has emphasized, the absolutistic conception is to be abandoned; reality is relative to an experimental situation, and the state of a microphysical system is to be viewed as an instrument for the statistical prediction of results of observation.

The conclusion to be drawn from the preceding discussion is that the relativistic conception of physical reality, which is required in quantum mechanics, constrains one to emphasize the instrumentalistic criterion of physical reality. From the quantum mechanical wave function which represents the state of a microphysical system, one can calculate the probabilities of the several possible results of observation. In view of the distinction between physical registration and perception, I mean by *result* the record upon the measuring instrument. A limiting case is that in which the probability of a specific result is certainty. Now, in Sec. I of this paper we saw that some macrophysical bodies are acknowledged to exist with relatively permanent properties. Such an object is a center of reference for perceptions, and serves as an instrument of prediction, with certainty, of perceptions. Accordingly, the criterion of physical reality employed in quantum mechanics may be extended to the whole of physical reality. A physical property is real if its observation can be predicted with certainty. The reality of the properties of a microphysical system resides in the certainty of prediction of physical effects which they may register on measuring instruments. The reality of such effects on macrophysical instruments ultimately resides in the certainty of prediction of perceptions belonging to them. The objectivity of the macrophysical world is based on its function in predicting perceptions for a community of observers.

[9] Naturwiss. **23**, 823 (1935).

Denver Meeting of the A. A. P. T.

TWO sessions of papers will be sponsored by the American Association of Physics Teachers at Denver, Colorado, on Thursday, June 24, 1937, in connection with the summer meeting of the American Association for the Advancement of Science. The morning session will be devoted to 10-minute contributed papers; abstracts not to exceed 300 words in length and in a form suitable for publication should be sent immediately to Professor W. B. Pietenpol, Department of Physics, University of Colorado, Denver, Colorado. The afternoon session will be devoted to a symposium of invited papers on "The Training of Secondary School Teachers of Physics." The following committee is in charge of the program: W. B. Pietenpol, University of Colorado, *Chairman;* H. A. Barton, American Institute of Physics; Paul Kirkpatrick, Stanford University; and J. C. Stearns, University of Denver.

The Pacific Coast Section of the American Physical Society will meet in Denver on June 21–25, and Section B of the A. A. A. S., on June 26.

Experiments on the Rate of Growth and Decay of Currents in Electric Circuits

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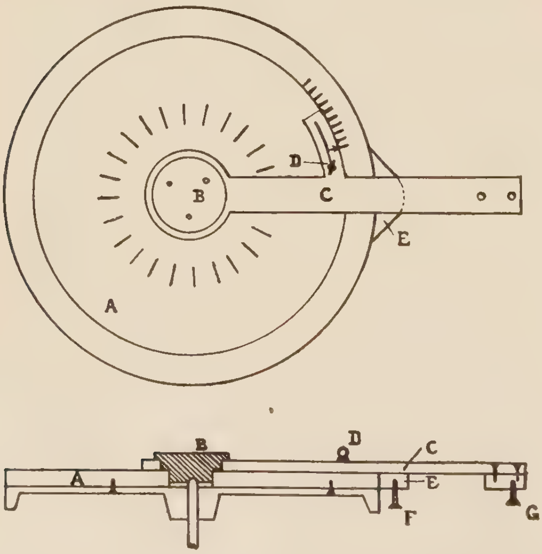
The essential feature of the experiments to be described is the use of a simple timing device, which enables an electric current to be measured a short time—1/360 sec. and upwards—after it is set up. The contacting system is easily constructed and is operated in conjunction with a phonograph motor and turntable.

A 12-in. disk *A* of five-ply wood is screwed to the top of a phonograph turntable by utilizing the holes usually existent in these turntables (Figs. 1 and 2). In the exact center of the disk a $\frac{3}{4}$-in. hole is bored and a piece of polar coordinate graph paper is pasted on the upper surface. A wooden plug *B*, accurately turned in a lathe, fits the hole so that the attached arm *C*, cut from three-ply wood, can rotate about the table center. A number of equidistant holes are bored around the circumference of the disk to enable the arm *C* to be clamped in any desired position by means of a screw eye *D*; its exact location is specified by setting a fiducial mark on the arm to a circular scale marked on the graph paper. A few divisions of this scale are indicated in Fig. 1. A wooden projection *E*, fixed to the edge of the turntable, carries a screw *F*. A second screw *G* is fixed similarly in the under surface of the arm *C*. These screws are utilized to operate separate switches. It is evident that when the turntable is rotating the time interval between the closing of the two switches can be varied by suitable adjustment of the position of the arm *C*.



Figs. 1 and 2. Turntable and contacting arms.

The two switches are identical in construction (Fig. 3). Each comprises a small brass trigger *H* which is displaced by the appropriate screw, *F* or *G*, when the table is rotated. The copper plunger *K* terminates in a "contacting" block, of about $\frac{1}{4}$-in. diameter, at its lower extremity. On the release of the trigger the plunger falls and the flat surface of the block makes intimate contact with a second copper block to complete an electric circuit. In order to minimize the fouling of the contacts it is necessary to break the circuit at another point, and this is effected by the mechanism used for restoring the contacts to their original positions. In any case perfect cleanliness is ensured by occasionally rubbing the contacts lightly with a piece of fine emery paper.

The two switches are mounted on a small wooden table *N* (Fig. 4) which slides in grooves cut in a wooden platform, the latter being rigidly fixed to a side of the phonograph box. Unless this table is pushed inwards the screws *F* and *G* (Fig. 2) do not trip the switch triggers; hence it is possible to ensure that the turntable is moving uniformly before the switching is performed.

A wooden board *O* is fixed perpendicularly to the underside of the platform, and a projecting wooden block *P* is screwed on it. This block carries the lower copper "contacting" blocks together with the necessary apparatus for restoring the contacts after the triggers have been tripped. Each of these copper blocks is soldered to a brass rod *Q* which passes through a brass tube fixed in the block *P*. Brass collars are placed on these rods together with springs to keep them in position. The rods are fixed to a wooden strip *R*, so that on raising *R* the whole contact system is also raised, but on lowering *R* the upper contacts remain held-up by the triggers. The strip *R* is raised by a crank situated behind *P* and connected to an ebonite strip *S* which carries a

screw at each end, so that on turning the strip in a clockwise direction it first separates the screws from the copper strips T and breaks the circuits. In this way the switch contacts are used only to make the circuits. On further rotation of the strip the crank restores the switches, the movement of the crank being communicated to R by a brass strip U. It is only when the spring V is pushed inwards that the triggers will make contact with the screws F and G on the phonograph turntable, and in this position the wooden block W (screwed on the remote side of N) impinges on a wire which is fixed below the turntable. At one point along its length the wire is turned upwards in the form of a loop and at its end is bent into the shape of a crank which presses against a brass block. Once every revolution the loop is caught by a screw fixed to the underside of the turntable and is turned slightly so that the end of the wire slips off the brass block. The wire can now be pushed inwards and the switch attachment slid into position for the operation of the switches. If the wire and the "catches" were absent, the switches might be operated in the wrong order owing to the attachment being pushed inwards at the wrong moment. To ensure the constancy of the speed of rotation of the turntable a stroboscopic disk is marked on the graph-paper scale and is observed by means of an incandescent, or preferably, neon lamp operating on the 50-cycle a.c. mains. The disk comprises 50 markings, only 24 being shown in Fig. 1, so that a constant speed of 2 rev./sec. is readily maintained.

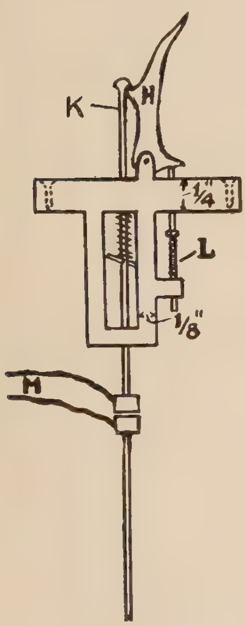


FIG. 3. Details of switch.

Calibration of the switching device. It is first necessary to ascertain whether the time interval between the tripping of the two triggers is repeatable and constant for a given setting of the arm C (Fig. 1), and whether the interval varies in a regular manner with the "angle of setting" of C, as measured from the position where the triggers are operated simultaneously. For this purpose a circuit is

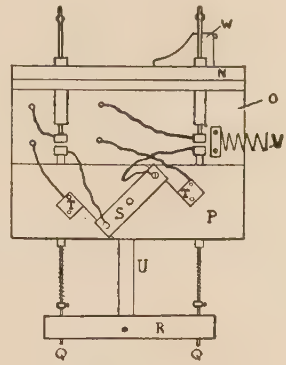


FIG. 4. Mounting of switches.

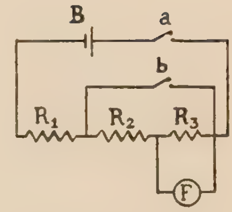


FIG. 5. Calibration circuit.

arranged as in Fig. 5, where a and b denote the two switches, B an accumulator, F a fluxmeter and R_1, R_2 and R_3, various resistances; R_1 is suitable to prevent damage to the battery B when the contact b is closed (a having been previously closed) and R_3 is a shunt to the fluxmeter.

When a is closed and b is open a small current is set up in the fluxmeter but it ceases on closing b, if R_2 has been suitably chosen. If a and b are now operated in succession by the rotating turntable, a quantity of electricity will flow through the fluxmeter which is directly proportional to the time interval between the release of the two triggers, provided the current in the circuit remains constant.

Let θ be the angular displacement of the arm C from its zero position, as previously defined, and let n be the number of rotations made by the turntable per second. Then the time interval t between the making of the two "contacts" by the switches is $\theta/360n$ sec. But the quantity of electricity Q which passes through the fluxmeter during this interval is equal to kit, where i is the current in the main circuit and k involves the shunt and fluxmeter resistances. It follows that $Q \propto t$, since i is kept constant, and hence $Q \propto \theta$. Now $Q \propto x$, the fluxmeter deflection; therefore $x \propto \theta$. Hence a plot of the angular settings of the arm C against the corresponding fluxmeter deflection should give a straight line (Fig. 6).

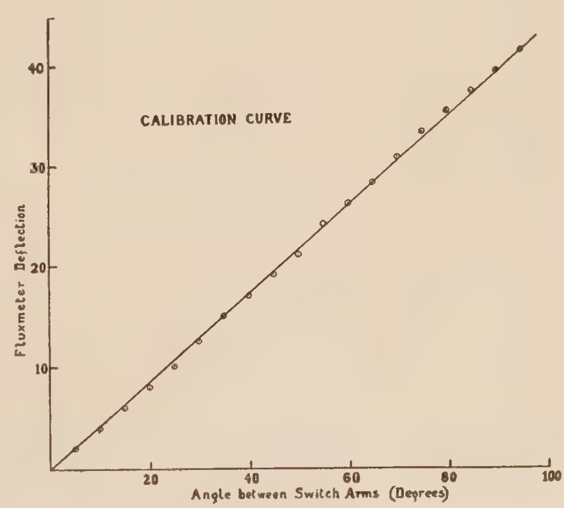


FIG. 6. Calibration curve.

Rise of the current in an inductive circuit. This effect can be shown in a simple manner by means of the circuit in Fig. 7. Here a and b are the switch "contacts," *M.A.* is an ordinary moving-coil milliammeter, K is a reversing key, B is an accumulator, and T is a mains transformer (of about 200 w capacity) consisting of a primary coil of 2000 turns of No. 22 copper wire wound on a Stalloy core 1-in. in cross section. The secondary coil of the transformer is adjusted to suit the sensitivity of the instrument and in this case consisted of 100 turns of wire. In the actual experiment it is arranged that contact a is closed before contact b, the time interval being suitably varied by adjustment of the switch arm C. If when b is closed the current in the inductance is still varying then the milliammeter will give a "kick." By varying the time interval of switching, a number of milliammeter readings are obtained from which a curve (Fig. 8) showing the growth of the current in the inductance can be constructed as indicated below.

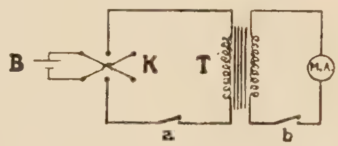


FIG. 7. Circuit for studying growth of current.

Let i be the value of the current in the primary winding at any instant t after closing a, so that the e.m.f. E induced in the secondary winding is given by $-Mdi/dt$, and the corresponding induced current I is $-(M/R)di/dt$, where M is the mutual inductance of the two windings and R is the resistance of the secondary circuit. It easily follows that since the quantity Q of electricity passing through the milliammeter is given by $\int Idt$ taken between the appropriate limits, then Q is proportional to $i_0 - i$, where i_0 is the final value of the current in the primary. Further, as Q is proportional to the deflection d of the milliammeter then d is proportional to $i_0 - i$, and again if d_0 is the deflection corresponding to $t=0$, and therefore $i=0$, then *$d_0 - d$ is proportional to i.* It should be carefully noted that the foregoing analysis is only approximate as, for example, the value of M has been assumed to remain constant for all values of i. Fig. 8, in which $d_0 - d$ is plotted against t shows that the current attains a value equal to 0.632 of its final magnitude after 0.228 sec. and this time therefore represents the time constant of the circuit.

With the same apparatus the experiment is repeated, except that the commutator is reversed for a few seconds between each reading. From these results Fig. 9 is drawn and it is obviously different in character from Fig. 8, indicating that no dependence can be placed on the latter when

FIG. 8. Curve for growth of current.

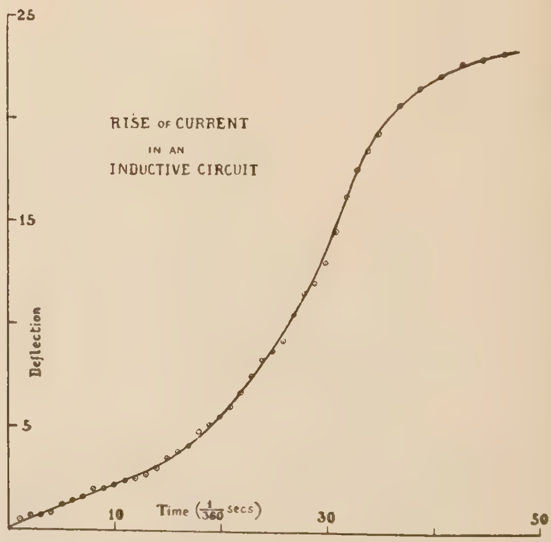


FIG. 9. Growth of current.

the impedance of the coil to a.c. is being considered.

Discharge of a condenser through a resistance and a small inductance. A condenser C of capacitance 7.9μf is discharged through a resistance R of 5500 ohms and a small inductance L (Fig. 10). The inductance consists of a solenoid approximately 11.5 in. long and containing about 90 turns of copper wire, the mean diameter of a turn being 1 in. approximately. The condenser is charged by depressing the key K. The measuring circuit consists of a search coil of about 600 turns, linked with the inductance L and a ballistic galvanometer G. The procedure is to charge the condenser and then allow it to discharge through the circuit by setting the timing apparatus into operation so that the contact a is made. After a predetermined time interval the contact b is closed and the galvanometer deflection is observed. The experiment is repeated for various settings of the switch arm C.

The equation of the discharge is given by

$$d^2i/dt^2+(R/L)\cdot(di/dt)+i/LC=0.$$

The values of L, C and R in the discharge circuit are such that $R^2/4L^2>1/LC$, and the discharge current i at any time t is therefore given by $-(E/\beta L)e^{-\alpha t}(e^{\beta t}-e^{-\beta t})/2$, where E is the charging potential, α is $R/2L$ and β is $[(R^2/4L^2)-(1/LC)]^{\frac{1}{2}}$. On inspection of the solution it is seen that the current i never changes in sign, and the maximum value is always less than $E/\beta L$. Hence the discharge current rises from $t=0$, reaches a maximum and then falls again to zero at $t=\infty$. These results are verified by experiment (Fig. 11).

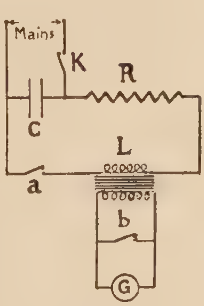


FIG. 10. Circuit for condenser discharge.

Now since L is small it may be possible to represent, at least for a portion of the discharge, the discharge current i by the expression $Ae^{-t/RC}$, which is the solution for the discharge of a condenser through a circuit containing only a resistance. Evidently, if this result holds, then a straight line should be obtained by plotting *log* i against t, provided the chosen values of t are not too small since, however small the value of L, it will at least determine the initial values of the current. As seen from Fig. 11 the logarithmic relation holds from A to B, but fails somewhat surprisingly for the larger values of t. This departure from the straight line over the region B to C is probably due to the time of discharge becoming rather too great for the accurate application of the ballistic galvanometer used in the experiment.

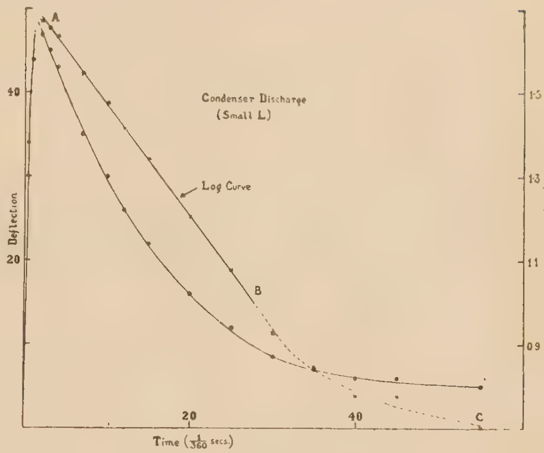


FIG. 11. Curve for condenser discharge.

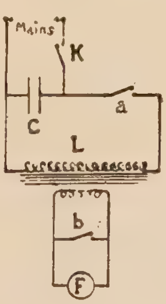
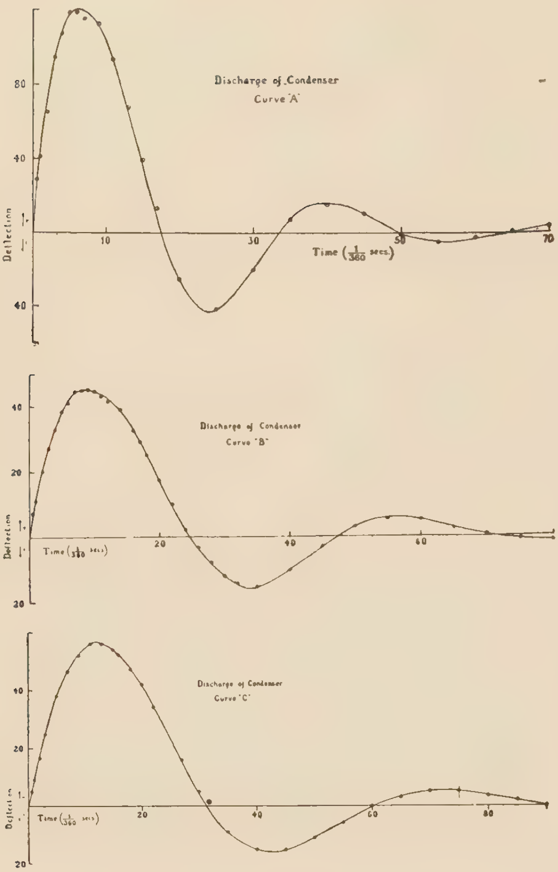


FIG. 12. Oscillatory circuit.

From the slope of the straight line AB it is found that $\log_e i/t=21.9$. But, since $i=Ae^{-t/CR}$, it follows that $\log_e i/t=-1/CR$, where $C=7.9\mu$f. Hence $R=10^6/(7.9\times21.9)=$ 5880 ohms, which is in fair agreement with the total resistance of the circuit when it is recalled that the value of R alone is 5500 ohms.

Oscillatory discharge of a condenser. In this case the values of L, C and R in the discharge circuit are such that $R^2/4L^2<1/LC$. The solution of the equation now becomes $i=-(E/\omega L)e^{-\alpha t}\sin\omega t$, where $\omega=[(1/LC)-(R^2/4L^2)]^{\frac{1}{2}}$, and it represents a simple harmonic motion, the amplitude of which decays exponentially with time. The period T of the oscillation is given by $2\pi/\omega$, and α is $R/2L$, the damping factor of the circuit.

The apparatus is shown in Fig. 12, where C is the condenser which is charged by depressing



FIGS. 13, 14 and 15. Oscillatory discharge.

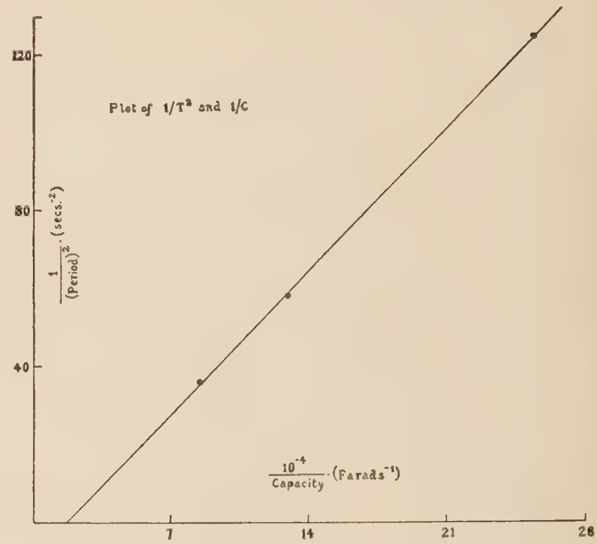


FIG. 16. Plot of $1/T^2$ and $1/C$.

the key K, and L constitutes both the inductance and the resistance. The latter actually consists of about 20,000 turns of enamelled copper wire, S.W.G. 34, wound upon an iron core composed of a bundle of soft iron wires 12 in. long and approximately 1 in. in diameter. A fluxmeter F is used as the measuring instrument and it is connected to a search coil of 100 to 300 turns of wire wound upon the coil L. The switch contacts a and b are made in the same order as in the preceding experiment. The procedure is identical, the deflections being now recorded by the fluxmeter. The experiment is repeated for at least three condensers of different capacitances, in this case approximately 4, 8 and 12μf, respectively. Figs. 13, 14 and 15, obtained by plotting fluxmeter deflections against time, show distinctly the oscillatory nature of the discharges.

It follows directly from the theory already given that $(4\pi^2L/T^2)+(R^2/4L)=1/C$. Assuming that L and R are constant, one sees that $1/T^2$ varies linearly with $1/C$, and further, if these quantities are plotted, the intercept on the axis of the variable $1/C$ is equal to $R^2/4L$. From Fig. 16 we find that the slope of the straight line is $4\pi^2L=1960$. Hence the effective self-inductance L of the circuit is 44.6 h. Further, the value of the intercept $R^2/4L$ on the axis of $1/C$ is equal to 1.68×10^4. Inserting the value of L just obtained we deduce that R is 1730 ohms.

Meeting of the National Council of Teachers of Mathematics

THE 18th annual meeting of the National Council of Teachers of Mathematics, held in Chicago on February 19–20, 1937, was the largest meeting in the history of the organization, the total attendance being in excess of 1000. There were several general sessions, a banquet, and three simultaneous meetings for the reading of papers. One section was devoted to mathematics in the junior college.

Motion Pictures Available for Use in Physics Instruction

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THIS list of motion pictures available for use in physics instruction has been compiled from a variety of sources and is thought to be fairly complete. Only those films have been included that appear from their titles and subject matter to lend themselves to use in physics.

Since available films vary greatly in their value for class use, the writer has evaluated those which he has seen and used as follows:

(*A*) Great teaching value; a day or more of work can be built around it.

(*B*) Some teaching value; contains extraneous material and material that is illustrative, rather than basic; usefulness for class instruction sometimes doubtful from point of view of economy of time.

(*C*) No teaching value.

The writer would like to assist physics teachers by collecting and compiling evaluations of these films. It will therefore be appreciated if users of the films will rate them *A*, *B* or *C* and send them to the writer by postal card or letter. To make this task as simple as possible, the films have been numbered. Information concerning any useful films omitted from the present list will also be welcomed. If there is a wide response to these requests, a revised list will be prepared and published.

University of Chicago Films. These films are designed primarily for the college level and the one that the writer has used is the best teaching film he has ever seen. Each subject is 1 reel, sound, either 16 or 35 mm. The sale and rental prices for each 16 mm film is $50 and $3.50 per day, respectively; for each 35 mm film, $100 and $5. For descriptive literature and purchase or rental arrangements, address Erpi Picture Consultants, 250 West 57th St., New York, N. Y.

1. *Molecular Theory of Matter*
2. *Electrostatics*
3. *Energy and Its Transformations*
4. *Sound Waves and Their Sources* (A)
5. *Fundamentals of Acoustics*
6. *Electrochemistry*
7. *Electrodynamics*
8. *Electrons*

Eastman Teaching Films. Eastman Kodak Co., Teaching Films Division, Rochester, N. Y. Designed primarily for the secondary school level. Each subject is silent, 16 mm only. The cost is $24 per reel and the films are not rented, except in isolated cases. These films are available in many localities through a clubbing plan. For example, in the case of one such club in western Pennsylvania, each participating institution buys one or more Eastman films and lodges them with the club together with a $10 deposit; the institution is then privileged to use each week as many films as it has placed with the club, a charge of 25 cts. being deducted from the deposit for each one used. A large number of schools and at least one college belong to this particular club.

9. *Atmospheric Pressure*, 1 reel
10. *Induced Currents*, 1 reel
11. *Chemical Effects of Electricity*, 1 reel
12. *Heat and Light from Electricity*, 1 reel
13. *Magnetic Effects of Electricity*, 1 reel
14. *Energy from Sunlight*, 1 reel
15. *Frequency Curves*, ½ reel
16. *Four Stroke Cycle Gas Engine*, 1 reel
17. *Glass Blowing Technique*, 2 half-reels
18. *Hot Air Heating*, 1 reel
19. *Illumination*, 1 reel
20. *Lenses*, 1 reel
21. *The Behavior of Light*, 1 reel
22. *Simple Machines*, 1 reel
23. *Optical Instruments*, 1 reel
24. *Refrigeration*, 1 reel
25. *Steam Power*, 1 reel
26. *Water Power*, 1 reel
27. *Weather Forecasting* (B), 1 reel

De Vry School Films. Designed mainly for the secondary school level. Each subject is silent, 16 mm only. May be purchased at $24 per reel from Herman A. De Vry, Inc., 1111 Center St., Chicago, Ill.; or rented from the Y. M. C. A. Motion Picture Bureau, 347 Madison Ave., New York, N. Y., the rental price per reel being $1.50 for one day, $2 for two days, $4 for five days. This rate is for the days the films are in use, ample time being allowed for transportation. These films are also available in some places through clubbing arrangements.

28. *Communication*, 1 reel
29. *Energy and Work*, 1 reel
30. *Principles of Magnetism*, 2 reels
31. *Principles of Electrostatics*, 2 reels
32. *Principles of Current Electricity*, 2 reels
33. *Principles of Electromagnetism*, 2 reels
34. *Principles of Current Generation*, 2 reels
35. *Principles of Electrical Measurement*, 4 reels

Bray Pictures Corporation, Educational Dept., 729 Seventh Ave., New York, N. Y. Silent, 16 or 35 mm. Available for rental or sale.

36. *Tides and the Moon*, 1 reel
37. *The Science of Weather Prediction*, 1 reel
38. *Experiments in Crystallization*, 1 reel
39. *Air Pressure in Which We Live*, ¼ reel
40. *Captured Electricity*, 1 reel

41. *Peculiarities of the Air*, ¼ reel
42. *Sound Waves*, ¼ reel
43. *Studies in Magnetism*, 1 reel
44. *Wireless Telephony*, 1 reel
45. *Mystery Box* (*Radio*), 1 reel
46. *How the Telephone Talks*, ½ reel

Edited Pictures System, Inc., 330 W. 42nd St., New York, N. Y. Silent, 16 mm. Rental, $1.50 per reel per day.

47. *Air*, 1 reel
48. *Fire and Heat*, 1 reel
49. *Atmosphere*, 1 reel
50. *Communication by Electricity*, 1 reel
51. *Current Electricity*, 2 reels
52. *Current Generation*, 2 reels
53. *Magnetism*, 1 reel
54. *Mysterious Forces*, 2 reels

"Rolab" Photo-Science Laboratories, Sandy Hook, Conn. Two reels, silent, 16 or 35 mm. For sale only, $25 per reel.

55. *Colloids and Their Behavior*

Kodascope Libraries, Inc., 33 W. 42nd St., New York, N. Y. Silent, 16 mm.

56. *Birth of a Tornado*, 1 reel
57. *Charting of the Skies*, Meteorological, 1 reel
58. *Einstein's Theory of Relativity*, 2 reels

Mogull Brothers, 1944 Boston Road, New York, N. Y. This company has a number of films available from time to time both for rental and sale; for example:

59. *Making of Dry Ice*, 1 reel, silent, 16 mm

Ideal Pictures Corporation, 30 E. Eighth St., Chicago, Ill., rental rate 60 cts. per day.

60. *Studies in Telephony*, 1 reel, silent, 16 mm

William H. Dudley, Inc., 736 S. Wabash Ave., Each subject is 2 reels, silent, 16 mm.

61. *Wireless Telegraphy and the Radio*
58. *Einstein's Theory of Relativity*, same as Kodascope.

F. C. Pictures Corporation, 505 Pearl St., Buffalo, N. Y.

62. *Velocity*, On Einstein's theory, 1 reel, silent, 16 mm

Wholesome Films Service, Inc., 48 Melrose St., Boston, Mass. Each subject is 1 reel, silent.

57. *Charting the Skies*, same as Kodascope, 16 mm
63. *Science of Bubbles*, 35 mm

Films of Commerce, Inc., 35 West 45th St., New York, N. Y. Each subject is 1 reel, silent, 16 or 35 mm. Rental rate per reel per day: 16 mm, $2; 35 mm, $4.

64. *Fair Weather Clouds*
65. *Foul Weather Clouds*
66. *The Mirage*

Society for Visual Education, Inc., 327 S. La Salle St., Chicago, Ill. These films were produced several years ago under the direction of Dr. Harvey B. Lemon of the University of Chicago. Each subject is silent, 16 or 35 mm. Rental rate per reel per day: 16 mm, $1.50; 35 mm, $2.

67. *Magnetism*, 1 reel
68. *Electrostatics*, 1 reel
69. *Electromagnetism*, 2 reels
70. *Electromagnetic Induction*, 1 reel
71. *High Frequency Currents*, 1 reel

Emerich Peters, 1491 York Ave., New York, N. Y.

72. *Waves and Wave Motion*, 7 partial reels, silent, 16 or 35 mm

W. M. Stempel, Stevens Institute of Technology, Hoboken, New Jersey. Sale price, 10 cts./ft. Rental: $10 per reel, $20 per subject.

73. *Wave Motion*, 3 reels, silent, 35 mm

The following films were produced by industrial concerns and are distributed as a service to educational institutions. They contain no advertising. They are loaned without charge; the borrower pays the transportation charges, usually both ways. It is advisable to request the films two weeks or more in advance as they are usually booked ahead. It is quite possible to arrange bookings for an entire semester or more.

General Electric Company, Visual Instruction Section, 1 River Road, Schenectady, N. Y. Requests for films should be addressed to the nearest branch office.

74. *Oil Films on Water* (B), in which Irving Langmuir describes his investigations, 5 reels, sound, 35 mm
75. *Radioactive Rays* (B), 1 reel, sound, 35 mm
76. *Hottest Flame in the World*, Irving Langmuir, 4 reels, sound, 35 mm
77. *Walter Damrosch* (C), ½ reel, sound, 35 mm
78. *The Steam Turbine*, 2 reels, sound, 35 mm
79. *Constitutions and Transformations of the Elements*, E. Rutherford, 2 reels, sound, 35 mm
80. *The Arrangement of Atoms and Molecules in Crystals* (B), W. H. Bragg, 4 reels, sound, 35 mm
81. *Theory of the Transformer*, 1 reel, sound, 35 mm
82. *Cathode-Ray Tube*, W. D. Coolidge, ½ reel, sound, 35 mm
83. *Mazda Lamps Preferred*, 4 reels, sound, 35 mm
84. *Early Experiments of Michael Faraday*, 1 reel, sound, 35 mm
85. *Life of Thomas A. Edison*, 1 reel, sound, 35 mm
86. *"Perpetual" Light*, demonstrates photo-tube controlled thyratron, 1 reel, sound, 35 mm
87. *A Modern Zeus*, artificial lighting, 1 reel, sound, 35 mm
88. *Liquid Air* (C), Film No. S2212, 1 reel, sound, 35 mm
89. *The Benefactor*, Thomas A. Edison, 2 reels, silent, 16 or 35 mm
90. *Revelations by X-Rays* (B), 1 reel, silent, 16 or 35 mm
91. *The Light of a Race* (B), 1 reel, silent, 16 or 35 mm
92. *Beyond the Microscope* (A), 1 reel, silent, 16 or 35 mm
93. *Wizardry of Wireless*, 2 reels, silent, 16 or 35 mm
94. *Thomas A. Edison*, 1 reel, silent, 16 or 35 mm
95. *Power Transformers*, 2 reels, silent, 16 or 35 mm
96. *Liquid Air* (A), Film No. 51, 1 reel, silent, 16 or 35 mm
97. *Big Deeds*, a trip through the Schenectady works, 2 reels, silent, 16 or 35 mm
98. *Mazda Lamp Manufacturing*, 2 reels, silent, 16 or 35 mm
99. *How the General Electric Icing Unit Works* (A), 2 reels, silent, 16 or 35 mm

Westinghouse Electric and Mfg. Co., Motion Picture Service, East Pittsburgh, Pa.

100. *Out of the Shadow*, street lighting, 2 reels, silent, 35 mm

101. *The Turbine with the Solid Rotor*, 2 reels, silent, 35 mm

102. *Magnalux Luminaire*, type of illumination, 1 reel, sound, 35 mm

103. *Westinghouse News Reel*, 1 reel, sound, 35 mm

104. *Diesel Electric Locomotives and Rail Cars*, 3 reels, sound, 35 mm

Western Electric Co., Motion Picture Bureau, 120 West 41st. St., New York, N. Y. Each subject is 16 or 35 mm; either size may be purchased but only the 35 mm size is available for loan.

105. *Finding His Voice* (A), how sound films are recorded and reproduced, 1 reel, sound

106. *Out Where the Sound Begins*, building of sound picture equipment, 1 reel, sound

107. *Engineering the Sound Film*, 1 reel, sound

108. *Sky Harbor* (C), 1 reel, sound

109. *The Voice that Science Made* (B), artificial larynx, 1 reel, sound

110. *Out of the Silence*, hearing aids, 1 reel, sound

111. *The Electrical Transmission of Speech*, 1 reel, silent

112. *Through the Switchboard*, 2 reels, silent

113. *A Telephone Call*, 1 reel, silent

114. *The Magic of Communication* (A), 1 reel, silent

115. *The Telephone Repeater*, 1 reel, silent

Bausch and Lomb Optical Co., Sales Service Dept., Rochester, N. Y.

116. *Eyes of Science* (A), 2 reels, silent, 16 or 35 mm

117. *Glass Magic*, silent, 16 or 35 mm

Chicago Film Laboratory, Inc., 1322 Belmont Ave., Chicago, Ill.

118. *The Principles of Magnetism* (B), 1 reel, silent, 35 mm

119. *House of Wonders*, made for the Elgin Watch Co., 2 reels, silent, 16 or 35 mm

Powers X-Ray Products, Inc., 205 West 39th St., New York, N. Y.

120. *New X-Ray Machine*, 1 reel, silent, 16 mm

Sperry Gyroscope Co., Brooklyn, N. Y.

121. *The Roll Control* (C), 2 reels, silent, 16 mm

Rowland Rogers Productions, 151 W. 46th St., New York, N. Y.

122. *T. C. Your Sixth Sense*, thermometry, 1 reel, silent, 16 mm

Massachusetts Institute of Technology, Visual Education Dept., Cambridge, Mass.

123. *Travelling Waves on Transmission Lines*, 2 reels, silent, 16 or 35 mm

United States Department of Agriculture, Division of Motion Pictures, Washington, D. C.

124. *Clouds*, 1 reel, silent, 16 or 35 mm

National Carbon Co., Madison Ave. and W. 117th St., Cleveland, O.

125. *The Story of the Carbon Arc*, 3 reels, sound, or 2 reels, silent, 16 or 35 mm.

Other Sources of Information Concerning Films

The best general source of information is the *1000 and One, The Blue Book of Non-Theatrical Films*, published by The Educational Screen, Inc. 64 East Lake St., Chicago, Ill. The price is 75 cts., or 25 cts. to subscribers of *The Educational Screen*, which is the only periodical on visual education published in this country.

Another good source of information is *Motion Pictures of the World*, published by the International Educational Pictures, Inc., 40 Mount Vernon St., Boston, Mass. There are two issues yearly for 50 cts. This company will book for the customer any of the subjects they list, the booking fee for free films being 25 cts. The catalog does not give the name of the distributor and so is not very useful unless the booking service is used.

The H. W. Wilson Co., 950 University Ave., New York, N. Y., publishers of the *Readers Guide*, is compiling an *Educational Film Catalog*. It will sell for \$2; or a two-years subscription may be obtained for \$4, and will include quarterly reports and an annual cumulation.

The Victor Animatograph Corporation, Davenport, Iowa, distributes free a list of 16 mm films with their source and other information.

The American Council on Education, 744 Jackson Place, Washington, D. C., has prepared a list of films on physics which is available to producers, distributors, and evaluating and research groups. Some of the films are described at length.

Current Releases of Nontheatrical Films, published by the Bureau of Foreign and Domestic Commerce, Washington, D. C., is a monthly list of new films, some of which deal with physical science. The price is \$1 per year.

In order to have full information the film borrower should make up his own file by obtaining the descriptive literature of the various distributors.

Mr. Spencer in the course of his remarks regretted that so many members of the Section were in the habit of employing the word Force in a sense too limited and definite to be of any use in a complete theory of evolution. He had himself always been careful to preserve that largeness of meaning which was too often lost sight of in elementary works. This was best done by using the word sometimes in one sense and sometimes in another and in this way he trusted that he had made the word occupy a sufficiently large field of thought.

Clerk Maxwell's humorous commentary on Herbert Spencer's appearance before the British Association in Belfast in 1874, as quoted by R. B. Lindsay and H. Margenau in *Foundations of Physics*.

APPARATUS AND DEMONSTRATIONS

A Laboratory Experiment on the Kinematics of Simple Vibratory Motion

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IN many beginning and intermediate courses the study of simple vibratory motion is limited to the presentation of the relationships,

$$x = A\cos\omega t, \quad (1) \qquad V = -A\omega\sin\omega t, \quad (2)$$

$$a = -A\omega^2\cos\omega t = -\omega^2 x, \qquad (3)$$

with the assignment of two or three problems involving each equation. Most of the ordinary laboratory equipment, such as a mass vibrating on a coil spring, is used in the study of a dynamical problem which really involves only Eq. (3), however. As a result the average student knows little about the kinematics of simple vibratory motion beyond the use of Eq. (3), which is stressed largely because of its use as a definition.

To aid in making Eqs. (1) and (2) have a real meaning the apparatus illustrated in Fig. 1 is suggested. A heavy pendulum bob B is suspended

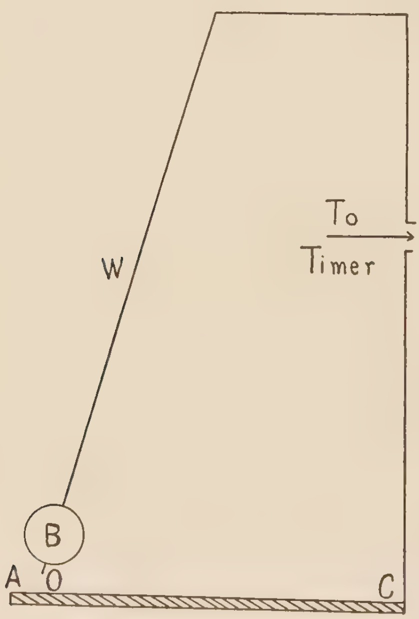

FIG. 1. Diagram of apparatus.

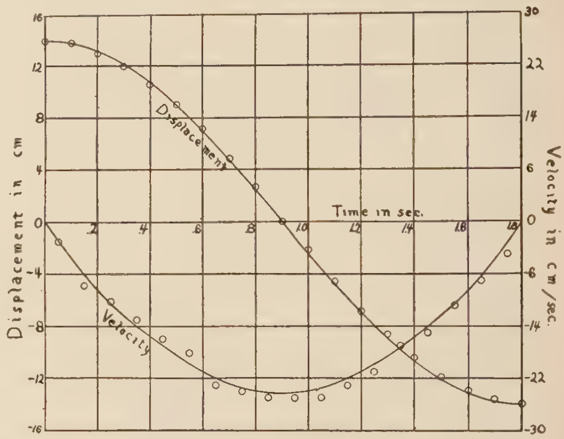

FIG. 2. Computed and experimental values of the displacement and velocity plotted as functions of the time.

from the ceiling by a wire W about 10 ft. long. On the bottom of B is a stylus O which swings so as just to clear a level metal plate AC. This plate and the wire W are connected to the terminals of a standard spark-timer which supplies pulses at definite intervals. The record is made by clipping a piece of sensitized paper onto plate AC.

If the pendulum be tied back a distance of approximately 6 in. (for a 10-ft. pendulum) from the equilibrium position and the thread burned the bob evidently will execute, to a very close approximation, linear simple vibratory motion. If, at the end of the swing, the timer switch be closed until a half-cycle is completed, the position of the bob as a function of time will be plotted on the sensitized paper, thus furnishing experimental data which may be checked against values calculated from Eqs. (1) and (2).

The amplitude is best determined by the direct measurement of the distance traveled by the bob. The equilibrium position may be determined in several ways, the simplest being to close the key of the timer before the pendulum is disturbed and to mark this point with a pencil. The value of the

period may be determined by timing a number of swings.

The method of checking the values calculated by means of Eq. (1) is obvious. Provided the time interval is made sufficiently short, Eq. (2) can best be studied by measuring the average velocity between two successive marks, and assuming that this is the instantaneous value of V at the mid-point of the interval and at a time-value t half-way between the end points.

The displacement and velocity curves in Fig. 2 are plotted from Eqs. (1) and (2) for an amplitude of 14 cm and a period of 3.6 sec. The points shown in Fig. 2 represent experimental values obtained by students. While the precision is not high the experiment serves to make the terms *amplitude*, *displacement*, *phase angle*, *period*, and *velocity* as applied to simple vibratory motion quite familiar to the student. The accuracy may be increased considerably by various refinements but these rob the experiment of its simplicity and hence of some of its value.

An Experimental Method for Obtaining Properties of a Section

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IN the design of columns and beams, the radii of gyration and moments of inertia and of area are required. It is often a matter of great difficulty in the case of irregular sections to obtain these values rapidly and accurately by the ordinary means of calculation. As integrators of the "Amsler" type are found in but few drafting rooms, the following pendulum method was devised, which has in its favor accuracy, speed, and availability of equipment.

Fig. 1 shows a metal section of uniform gage, mounted as a pendulum. The radius of gyration k about the axis of rotation is given by the equation

$$k=(T/2\pi)\sqrt{(gd)}, \qquad (1)$$

where T is the period, g is the acceleration due to gravity, and d is the distance between the axis of rotation and the parallel centroidal axis. The pendulum is swung with a very small amplitude in still air, the period T found by timing 100 vibrations, and k computed from Eq. (1). The center of mass may be found by balancing the specimen in several positions on the edge of a triangular boxwood scale. The moment of inertia I_c and radius of gyration k_c about the parallel centroidal axis are computed from the equations $I_c=Mk^2-Md^2=Mk_c^2$, where M is the mass of the specimen, obtained on a balance by the method of double weighing. If the density ρ of the specimen is known and its gage w is found with a micrometer caliper, the moment of area $Mk^2/w\rho$ may be computed.

Two gages were used—0.065 and 0.075 in. The specimens need not be this thin, however; with a specimen 8 in. square a thickness of 0.25 in. can be used without introducing errors of importance, and such heavier specimens reduce some difficulties. The specimen shown in Fig. 1 is 7.5 in. wide and 5.5 in. high, overall. The experimental specimens are considerably larger than those furnished by manufacturers, the latter being too small to be practicable for the experiment. Consequently, if values for manufacturers' specimens are desired, "scale factors" must be employed to reduce the data. The number painted on the specimen in Fig. 1 is that of the original model, selected from a catalog of the Aluminum Company of America.

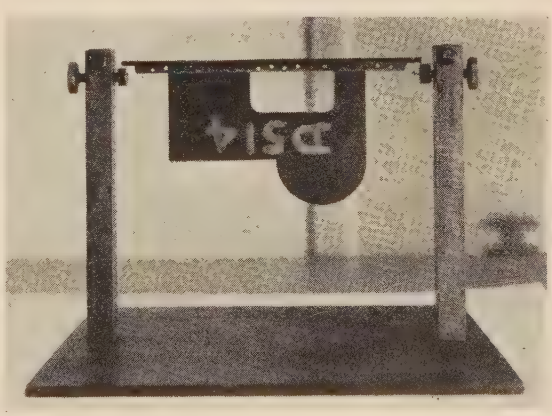

FIG. 1. Photograph of the apparatus. Its height is 11 in., and width, 12 in.

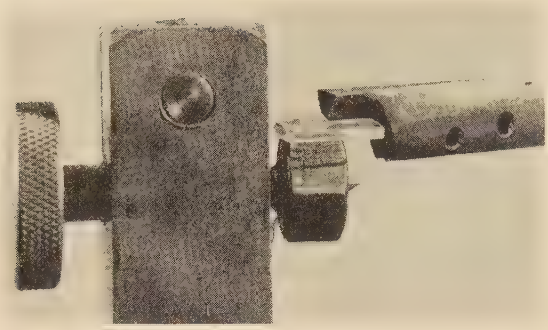

FIG. 2. Details of the bar and bearing surface.

The method of mounting shown in Fig. 1 was found to be the most satisfactory. The bar supporting the specimen is made of machine steel, and has a longitudinal groove slightly narrower than the gage of the specimen, so that the latter is held fast in the bar under slight compression. The bar is drilled to lighten it and afterwards ground down for balance and further reduction in weight. The knife-edge bearings are on a line with the bottom of the groove in the supporting bar. The bearings rest on glass (Fig. 2) cemented to nuts which can be adjusted by turning a knurled thumb-wheel, thus affording a means of leveling the bar.

TABLE I. *Moments of area of specimens.*

Specimen	Moment of area (in.⁴) Experiment	Moment of area (in.⁴) Calculation	Percent difference
(*a*)	0.00474	0.00474	0.0
(*b*)	0.00160	0.00160	0.0
(*b*)	0.00970	0.00968	0.2
(*c*)	0.00366	0.00362	1.1
(*d*)	0.04680	0.04700	0.4
(*e*)	12.8	13.3	3.9

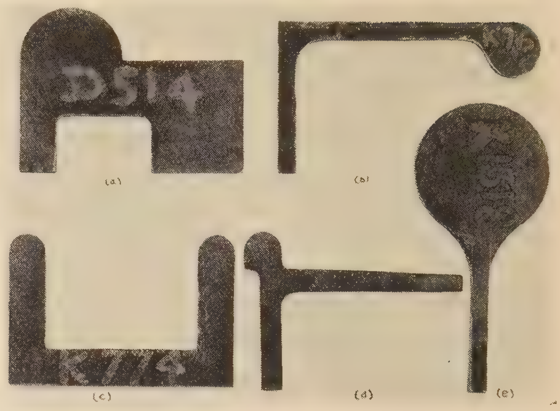

FIG. 3. Photographs of specimens tested.

Various types of specimens tested are shown in Fig. 3 and their moments of areas as obtained both by experiments and by the ordinary method of calculation are given in Table I. All data are for horizontal axes through the centers of mass, except that for specimen (*b*) the second data are for a vertical axis through the center of mass. The percentage of difference for an easily calculated specimen—an 8-in. square—was found to be 0.24 percent. From a comparison of this value with the percentages of differences given in Table I, it appears that the reliability of ordinary calculations is frequently doubtful. Many students have determined the moments of area of the five shapes shown in Fig. 3, both by the long arithmetical method and by the shorter pendulum method. It rarely happens that their calculated values agree exactly, whereas the experimental values are closely duplicable. Because of their reliability, the pendulum values were chosen for the denominator in computing the percentages of difference in the tabulated results.

Summer Courses in Photography at Rochester

TWO courses in photography will be given this summer under the joint auspices of the Institute of Applied Optics of the University of Rochester and the Eastman Kodak Research Laboratory. These courses will be similar in nature to those given in the regular curriculum of the Institute of Optics. The elementary course will run from June 22 to July 13; the advanced course, from July 5 to July 23. During the week that the courses overlap, topics common to both (the making of emulsions, color photography, etc.) will be covered. Registration may be for either one or both courses.

The lectures in the advanced course will be given by Dr. C. E. K. Mees, Dr. L. A. Jones and Dr. Walter Clark of the Kodak Research Laboratories. This course will cover such topics as the production and physical characteristics of the developed image, the theory of tone reproduction, the nature of the latent image, color sensitive emulsions, filters and various methods of practical sensitometry. In addition, there will be an opportunity for those wishing to gain some acquaintance with the technics in two specialized fields: "Photographic Photometry and Spectrophotometry," by Dr. Brian O'Brien, July 5–9; "The Photographic Emulsion as a Tool in Atomic Nuclear Research," by Dr. T. R. Wilkins, July 12–16.

Trips of inspection of the Kodak Park Laboratories and the Kodak Camera Works will be featured. A detailed announcement may be obtained by addressing the Institute of Applied Optics, or the Director of the Summer Session of the University of Rochester. The courses will be under the immediate supervision of Doctors Wilkins and Clark.

A Mechanical Model of a Vacuum Tube Amplifier

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THE value of a mechanical model lies in its ability to coordinate a number of ideas about any particular subject, and to provide a point of departure in evolving new correlated facts. One must not ignore the limitations of any model, however. The model of a vacuum tube power amplifier described here is simple and, seemingly, very obvious. Yet the author has found it to be effective in making clear some of the fundamental characteristics of the amplifier.

A small rodent trap *A* is mounted on a stout board above a larger trap *B* (Fig. 1). A string *S* passing through eyelets connects the spring of the small trap to the trigger of the larger trap. The spring of the latter trap is connected by a stout cord to a 5-kg weight *W* which rests on the edge of a nearby chair or table. Both traps are set. A small weight *w*, attached to a string, is then lowered until it touches the trigger of trap *A*, thus releasing the spring. The movement of this spring is transferred by means of the string to the trigger of the larger trap *B*. The heavy spring, upon being released, drags the weight *W* from the chair. It falls to the floor.

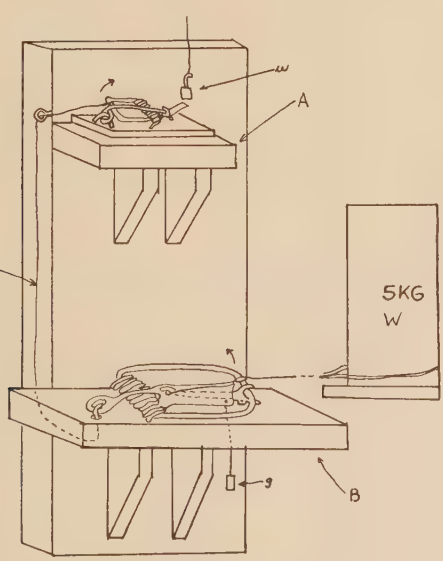

FIG. 1. Diagram of model.

Basically, the model shows how a small impulse or signal voltage *w*, applied to the grid of the input tube, may release or control a large amount of energy in the output of a power tube *W*. The trigger of each trap is the grid of the tube, while the energy in the plate circuit is represented by the energy in the spring. The output of the first trap must excite the input or trigger of the second stage or larger trap.

The following points are in evidence:

(1) There is a minimum grid-voltage input for an amplifier. Thus, *w* can be made so small that trap *A* is not sprung. The first trigger, if too sensitive, would be released by the vibrations of one's steps in approaching it. In an amplifier, the sensitivity must be no less than several microvolts; otherwise, the "shot effect" and thermal effects would produce a background of noise.

(2) The coupling between the stages is represented by the string *S*. Thus, the slack in *S* can be so great that trap *B* is partially or entirely unaffected, thus preventing it from operating.

(3) In a power amplifier, the first tubes need only be voltage amplifying tubes which are to provide the large grid swing in the power tube. This large grid swing causes energy to be dissipated in the load. Here, the first trap is a light trap to provide a large swing to the second, larger trap. Since the larger trap is really quite sensitive, requiring a very small displacement of the trigger to release the spring, the trigger here has been given a small load *g* to make it more analogous to an amplifier.

(4) There is an optimum load *W* for the amplifier. If *W* is too small, trap *B* will spring very rapidly, and the energy is spent in the trap rather than in the load. Too large a load, on the other hand, prevents the operation of the trap. The tension of the spring will exist in the string. Thus, if too large a load or resistance is used in the plate circuit of a vacuum tube, the plate voltage will become practically zero and the tube cannot operate. This is due to the large potential drop over the load which will almost equal the supply-voltage. If the load on the large trap is too large, the total force of the spring will be on the cord to the load but the energy will not be released.

(5) The larger movement of the spring on trap *A* causes the trigger of *B* to move farther than the trigger of *A*. Therefore, the bias of each succeeding tube in an amplifier must be generally higher as well as its corresponding plate voltage so that the grid-swing will vary the plate current over the straight part of its grid voltage-plate current characteristic.

The foregoing treatment obviously can be varied to meet the requirements of the class.

Auxiliary Apparatus for the Elementary Experiment on the Potentiometer

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ONE of the common elementary experiments in electricity deals with the use of the slide-wire potentiometer. The catalogs of the various apparatus makers indicate the widespread interest in this basic experiment. In the experiment usually performed, the student is confronted with a maze of wiring that masks the main purpose for which we use the experiment—the acquisition of information concerning the operation of the potentiometer.

The author has devised auxiliary apparatus (Fig. 1) that dispenses with the most of the wiring usually demanded of the student, and that is permanent in form, inexpensive, and practically fool-proof. While the units were designed for a particular type of slide-wire potentiometer made by the W. M. Welch Manufacturing Company, they may easily be adapted for use with any of the simple types on the market.

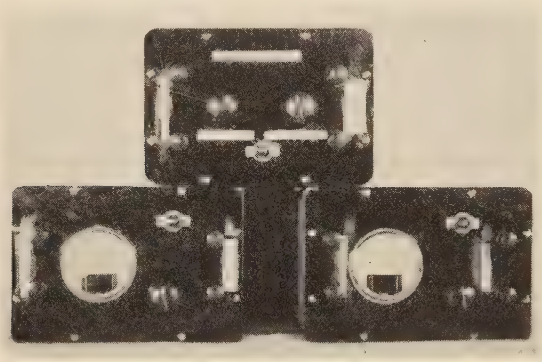

Fig. 1. Photographs of potentiometer control box (top), 0–3 v voltmeter test unit (left), and 0–400 ma milliammeter test unit (right).

One unit, termed the control box (Fig. 2a), serves to regulate the potentiometer current. To prevent damage to the potentiometer through overheating, a fixed resistance is employed in conjunction with a parallel arrangement of two radio-type variable resistances. The connections to these variable resistances are so made that rotation of the resistance dial causes the galvanometer needle to move in the same sense. In addition, the lack of sufficient external voltage for the potentiometer circuit is indicated by inability of the experimenter to obtain an exact balance. Since the current is small, dry cells may be employed as the source of voltage. A single dry cell may also be used satisfactorily as the "standard cell," its e.m.f. being previously determined with a precision potentiometer, or even with a high resistance voltmeter if extreme accuracy is not desired.

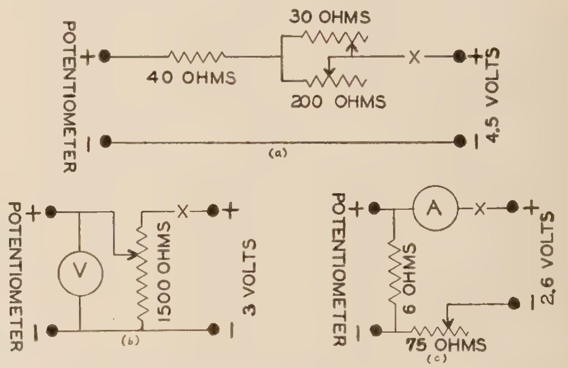

Fig. 2. Wiring diagrams for (a) potentiometer control box, (b) voltmeter test unit, and (c) ammeter test unit.

The remaining two auxiliary devices are the voltmeter and the ammeter test units (Fig. 2, b and c). The customary wiring is employed, except that the units are permanently assembled and only four connections need be made by the student. Inexpensive panel-type radio meters are used.

The use of these auxiliary units does not afford the student much experience in connecting electrical apparatus in a circuit. For this reason, additional experiments should be provided, in which the student is required to do the wiring himself. It is felt, however, that the student's first introduction to the potentiometer is more impressive when stripped of all but the bare essentials.

An Audio-Oscillator Having an Air-Core Inductance Coil

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THE thermionic oscillator is a convenient and versatile source of adjustable-frequency alternating current. However, as ordinarily constructed it often has two faults, frequency drift and poor wave form. Designs in which these faults are corrected are apt to be elaborate and correspondingly expensive. The circuit to be described is inexpensive and easily constructed, its stability and freedom from harmonics are adequate for all but the most exacting applications, and it may be modified readily to use other tubes, with a.c. power supply if desired. Students find it easy to understand, adjust, and operate.

Fig. 1 shows the circuit. The only special piece of equipment is the 10-h air-core inductance coil of Maxwell cross section[1] shown in Fig. 2. Its design is such that maximum inductance is secured with a given amount of wire. This coil is tuned with a 1-μf 3-decade condenser in parallel with a 0.0011-μf variable condenser. Frequencies from 64 to 2048 cycles/sec. are obtained without changing inductance taps.[2] This simplifies operation, and reduces the possibility of mistakes in using the calibration curve (Fig. 3). It will be noted that much of the curve is linear, having a slope of $-\frac{1}{2}$; over this range the approximate expression $t=2\pi\sqrt{(LC)}$ is therefore applicable. The four milliammeters, which may be small and inexpensive, will provide a convenient check upon circuit conditions; M_3 and M_4 may be omitted without serious inconvenience.

[1] *Dictionary of Applied Physics* (Macmillan, 1923), Vol. II, p. 417.

[2] The low range may be extended to 45 cycles by adding external capacitance.

Frequency drift and poor wave form in the output of a thermionic oscillator are, of course, due to variations in the impedances of the tube or of its associated circuit. The inductance and a.c. resistance of the air-core coil shown in Fig. 2 have no appreciable cyclic variations and only small temperature coefficients. Changes in the input impedance of the tube are minimized by not allowing appreciable grid current to flow.[3] Changes in its output impedance are kept small by operating it at high plate voltage and low grid bias, and by restricting the excursions of the grid potential to small amplitudes. Its dynamic characteristic is thus made to approach in shape an ellipse of large eccentricity.[4] A Fourier analysis of the wave forms corresponding to two such curves[5] predicts that harmonic distortion may thus be reduced, even-order partials being more affected than those of odd order. This prediction has been verified experimentally.[6]

The use of direct coupling from the tuned circuit to the amplifier stage provides a less distorted signal than would be obtained by other methods. That this is true may be seen from the following considerations. The free oscillations of the tuned circuit are nearly sinusoidal. In order to maintain them at constant amplitude, the energy fed back from the plate circuit must exactly replace losses.

[3] The grid current is about 5μa; i.e., it is identical with that drawn when the circuit is not oscillating.

[4] H. J. van der Bijl, *The Thermionic Vacuum Tube* (McGraw-Hill, 1920), p. 175.

[5] Author, M.S. thesis (Univ. of Pittsburgh, 1934); J. Lipka, *Graphical and Mechanical Computation* (Wiley, 1918), p. 181.

[6] T. J. O'Donnell and V. E. Thornburg, B.S. thesis (Carnegie Inst. of Tech., 1933).

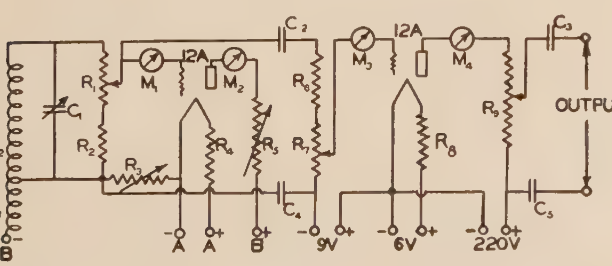

FIG. 1. Circuit diagram. L_1, L_2, Maxwell inductance coil; C_1, 1-μf 3-decade condenser in parallel with 0.0011-μf variable condenser; C_2, C_4, 0.5μf; C_3, C_5, 4μf; R_1, R_7, 0.5 megohm; R_2, R_6, 50,000Ω; R_3, 2000Ω; R_4, R_8, 4Ω; R_5, R_9, 10,000Ω; M_1, M_3, 0 to 1 ma; M_2, M_4, 0 to 15 ma; $A+$, $A-$, 6 v; $B+$, $B-$, 135 v.

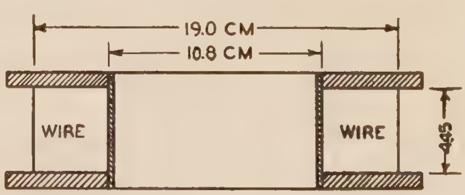

FIG. 2. Maxwell air-core inductance coil. Wound with 7500 turns (about 10 lb.) of No. 26 B & S enameled copper wire; d.c. resistance, 530Ω. Tapped at 2450 turns from start of winding (feedback coil is this inner portion). Total inductance 9.95 h. L_1, 2.25 h; L_2, 3.50 h; M, 2.125 h; coefficient of coupling, 0.75. Wooden coil form; core is slotted brass tube.

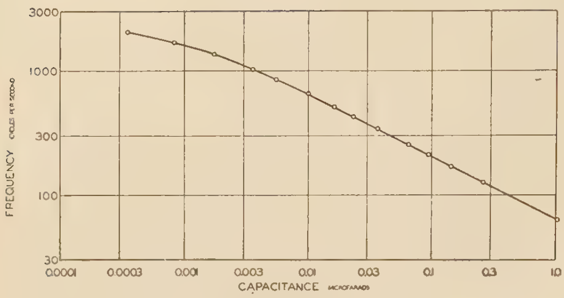

FIG. 3. Calibration curve.

Hence, if losses are small, we may regard the total oscillation current as the vector sum of two unequal alternating currents having the same frequency, the larger a pure sinusoid due to the resonant circuit, the smaller containing a fundamental and a series of harmonics due to the plate circuit. Obviously the total oscillation current is less distorted than is that in the plate circuit alone. Therefore it will pay to excite the amplifying stage from the resonant circuit if minimum distortion is desired.[7]

The best wave form obtainable with the circuit of Fig. 1 is secured by adjusting R_1 until the input to the grid is barely large enough to maintain oscillations. R_3 is set at the point where the tube oscillates most easily; in our set-up this occurs at about 1500 ohms. (The usual bypass condenser across R_3 is omitted, since the alternating potential difference across this resistance merely assists in the desired restriction of oscillation amplitude.) R_5 is left at maximum, because of its favorable effect on wave form,[8] unless the circuit is tuned to such a low frequency (less than 70 cycles) that it will not oscillate with R_1 set to maximum. R_5 must then be reduced until oscillations just begin.

When the circuit is properly adjusted, the grid meters will read zero, and the plate meters will read almost exactly the same as they did before oscillations started. Under these conditions, the maximum no-load output is about 25 v rms at all frequencies. This naturally follows from the prescribed adjustment, for the oscillation crest amplitude is manually set equal to or very slightly less than the steady grid bias. The power output is sufficient to allow direct connection to a loudspeaker, a bridge, or an oscilloscope.

The maximum power output to a noninductive load is 0.1 w into 10,000 ohms. If more is wanted, a separate class *A* push-pull stage of good design should be added. A local laboratory has constructed an oscillator after this design using push-pull 56 oscillators, a push-pull 56 interstage, and a push-pull 50 output. This delivers 4 w into 4000 ohms. It should be pointed out that an amplifying stage may easily introduce more distortion than was present in the original output of the oscillator unless it is generously designed and conservatively loaded.

Because of its stability and good wave form, this oscillator is particularly suitable for the demonstration of Lissajous figures with the aid of a cathode-ray tube.[9] The 1:1 ratio furnishes a fairly sensitive test for distortion, either the circular or the linear phase readily showing departures of either component from the true sine form.[10] The stability of the oscillator is such that the automatic frequency adjustments on a clock controlled 60-cycle line are easily observable after an approximately stationary figure has been secured. If the output of a well-designed electrically driven tuning fork is used, any Lissajous figure may be held stationary or allowed to drift slowly through its phases. By observing the rate of drift we can measure the changes in oscillator frequency caused by alterations in battery supply voltages. A decrease of 30 percent in plate potential or of 10 percent in filament potential will cause a decrease of 0.1 percent in oscillation frequency. Such tests may be made after a warming-up period of 5 min. Further warming is unnecessary.

Table I gives distortion percentages, measured by Suits' method,[11] and comparison-results from a similar circuit using an iron-cored inductance coil. In both cases the input to the measuring circuit was held constant at 5 v rms. The

TABLE I. *Relative harmonic amplitudes in outputs of air-core and iron-core oscillators of similar design.*

Oscillator	Frequency (cycles/sec.)	1	2	3	4	5
Air	128	100	3.2	2.4	<0.1	<0.1
Iron	128	100	2.1	19.6	1.5	4.8
Air	256	100	4.5	1.6	<0.1	<0.1
Iron	256	100	2.5	19.1	1.7	4.1
Air	512	100	3.2	4.7	<0.1	<0.1
Iron	512	100	2.2	19.6	Not determined	

[7] F. E. Terman, *Measurements in Radio Engineering* (McGraw-Hill, 1935), p. 285.
[8] Reference 4, p. 170.

[9] J. H. Morecroft, *Electron Tubes* (Wiley, 1933), p. 435.
[10] P. H. Osborn, M.S. thesis (Univ. of Pittsburgh, 1932).
[11] C. G. Suits, Proc. I. R. E. **18**, 178 (1930).

fundamental is designated as 1, the harmonic of double frequency as 2, etc. These measurements were made in the course of determining the best operating conditions for minimum distortion. It is now known that certain adjustments of R_3 and R_5 will further reduce either odd-order harmonics or those of even order, but not both together. A push-pull oscillator so adjusted that odd-order harmonics are minimized might be worthwhile for special applications. The large odd-order harmonics due to the iron core will be noted.

The author gratefully acknowledges the help of Messrs. J. T. McCartney and H. S. Seifert,[12] who did the development work, Messrs. T. J. O'Donnell and V. E. Thornburg,[6] who made a careful analysis of wave forms, and Professor George A. Scott, under whose direction a preliminary investigation[5] was made.

[12] B.S. thesis (Carnegie Inst. of Tech., 1933).

Demonstrating the Rotating Field

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IT is frequently desirable to have available a means of demonstrating a rotating[1] field vector. In particular, in the discussion of the polyphase induction motor, exhibition of the inverse Arago effect and then of the induction motor with a disk armature leaves a gap which might profitably be filled in; namely, the display of evidence that a rotating field can indeed be produced in the way in which we say it can—that the disk is not turning for some other perhaps unknown causes.

The development of the cathode-ray oscillograph, and its production at a price which places it within the means of most laboratories, has furnished a way of showing that a field mechanism such as that of a two-phase induction motor does produce a field which rotates. Furthermore, either an electric or a magnetic field can be shown, accordingly as one uses plates or coils for deflection. The space quadrature which must coexist with quadrature in time between the two fields is furnished by the characteristic orientation of the two sets of deflecting plates in the cathode-ray tube, or by the suitable placing of the two sets of coils. It must be remembered, however, that if the magnetic case is demonstrated, the electron deflections will be perpendicular to the field and to the path of the electrons.

A circuit for exhibiting the rotating electric field, which is usually the handier to produce because the deflecting plates are inherent in the tube, is shown in Fig. 1(a). The two sliders are intended to be moved not too rapidly back and forth along their respective coils with simple harmonic motions of equal period and with one always lagging behind the other by 90°. The resulting pattern on the oscillograph screen is a spot slowly tracing out a circle as the sliders are moved. This spot is supposed to represent one end of the field vector, which passes through the origin.

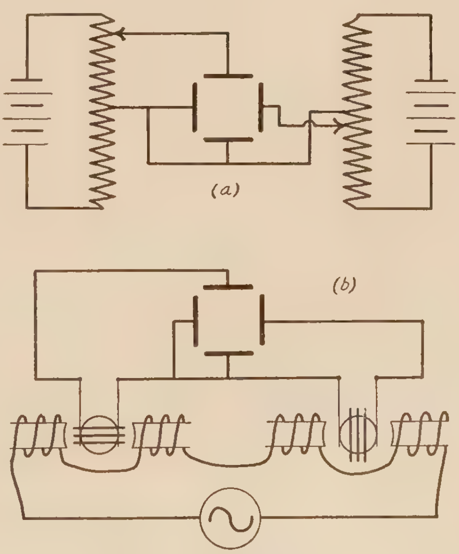

Fig. 1. Wiring diagrams.

[1] The kind of field encountered in the polyphase induction motor is spoken of sometimes as "revolving" and sometimes as "rotating." Is it not better to maintain the astronomer's discrimination between these terms, reserving the former for cases where the turning is about another body, or at least about an external axis? With this distinction we might call the field in an induction watt-hour meter a *revolving field*, but we should allude to the field in an ordinary two-phase induction motor, for instance, as a *rotating field*.

A deterrent to the success of the demonstration lies in the symbolism of a dot for a vector. It is desirable, therefore, to modify the situation so as to obtain a line to represent the field vector, the rotation of this line giving a clearer impression of the phenomenon involved. This effect is obtained by applying an alternating potential difference to the "potentiometers" instead of a direct one.

It is worth noting that the two coils can be connected to the same source of potential difference. In fact, if a coil is available with two separate sliders (which must be able to pass each other), it may be used instead of the two coils. Since coils having a center tap as well as a slider are rare, the central connection from the two common deflecting plates will usually have to be made to an additional resistor connected in parallel with the two shown, and preferably of the same order of resistance. The resistance of the coils should be sufficiently large to limit the current with whatever voltage is found necessary to give convenient deflections with the particular oscillograph used.

The weakness of the apparatus as so far described is in the difficulty in moving the sliders with simple harmonic motion and in keeping them in quadrature. It is possible to do this by means of a mechanical arrangement, using a wheel having projecting pins, but the following is a much neater method.

The field coils of two K. & D. model dynamos are connected to the alternating current source in series with each other, as in Fig. 1(b), each acting as the primary of a variable transformer. The secondary of each of these transformers is an armature (with slip-rings, not commutator segments) with a single winding which can be rotated so as to be "threaded" by any amount of flux between zero and the maximum afforded by its area-turns. If the field is uniform, though varying sinusoidally, and one of these armatures is rotated with a constant angular speed while the other is set to intercept zero flux, the resulting pattern on the oscilloscope screen will be a line whose length varies sinusoidally; in other words, a representation of the field vector of a simple alternating field, either electric or magnetic, according to the means of deflection. It is well to establish this point firmly with students before proceeding with the superposition of fields. It will readily be seen that the rotation of both armatures at the same constant angular speed, with one kept 90° behind the other (conditions which are easily obtained by belting them together), will produce two fields which are in quadrature in both time and space, thus yielding a rotating line on the oscillograph screen.

The demonstration is kept more simple by rotating the armatures by hand. There is of course considerable departure from uniformity of field in the dynamos, resulting in departure from circularity in the area swept out on the screen. This distortion can be made small by using armatures without cores. If one wished to be particular, it could be obviated by constructing field coils in the Helmholtz arrangement. The presence of the distortion and its explanation, however, seem to have value in bringing out points regarding dynamo construction.

It is worth while to point out that reversal of the direction of rotation of the field can be obtained either by reversing the direction of rotation of the belted armatures or by displacing one of the coils through 180° with respect to the other. After demonstrating with the apparatus of Fig. 1(b), it is often profitable in order to fix ideas to show the method of Fig. 1(a), with direct voltage, as a problem for the student to explain.

By using three sets of deflecting coils and three of the variable transformers, it is possible to demonstrate a three-phase rotating field, in this case a magnetic field.

The apparatus here described has applications in the synthesis of other dynamic phenomena difficult of visualization, and in the synthetic interpretation of the sequences of figures produced in investigations using the cathode-ray oscillograph.

If Davy had not been the first chemist, he would have been the first poet of his age.

—Samuel Taylor Coleridge

DISCUSSION AND CORRESPONDENCE

Errors in Textbook Curves for Black Body Radiation

WE feel it worthwhile to call attention to certain erroneous conceptions regarding the Planck and Rayleigh-Jeans distribution functions for the radiation from a black body which have become common in textbooks.

Introducing $x=kT\lambda/hc$ and $K=8\pi(kT)^4/(hc)^3$, we may say that the energy in the radiation between x and $x+dx$ is $Kf(x)dx$, where

$$f(x)=1/x^5(e^{1/x}-1) \qquad \text{(Planck)} \quad (1)$$

or

$$f(x)=1/x^4 \qquad \text{(Rayleigh-Jeans).} \quad (2)$$

If we plot the two functions against x, which is proportional to λ, the two curves shown in Fig. 1 are obtained. The curve for the Rayleigh-Jeans function as given in textbooks is frequently incorrect in its relation to the curve for the Planck function. The curves A, B, and C, which are taken from three well-known textbooks, are examples of incorrect curves. Because of the persistence of incorrect curves in the literature, it is believed by many physicists that the Rayleigh-Jeans and Planck curves agree quite well at long wave-lengths or at large values of x. It is true that the two curves do agree at long wave-lengths, but how long are these wave-lengths? According to curve A, one would be led to believe that the agreement occurs at a value of x only slightly larger than x_m, where x_m is the value of x for the maximum of the Planck curve. However, the truth is that the ordinate of the Rayleigh-Jeans curve is still twice that of the Planck curve when x is nearly four times x_m. It is not until x is nearly 25 x_m that the difference between the curves is reduced to 10 percent. Thus to say that the curves agree at long wave-lengths is a very loose statement of the truth. Moreover, the all too common belief that the agreement between the Rayleigh-Jeans and Planck curves becomes better at sufficiently low temperatures is a misconception, since the agreement between the two curves for a given value of x or of x/x_m is independent of T. The curves of Fig. 1 represent the situation just as well for a temperature of 1°K as for a temperature of 2000°K.

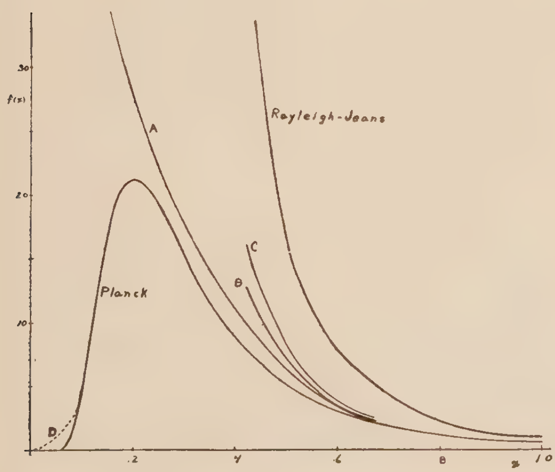

FIG. 1. The Planck and Rayleigh-Jeans curves.

An error in the shape of the Planck curve near the origin was found in one textbook and is shown by the dotted curve D in Fig. 1. There is no such gentle "tailing off" in the Planck function; rather it falls rapidly towards the axis of x as shown in Fig. 1. The ratio $f(x)/f(x_m)$ at $x=0.25\ x_m$ is of the order of 10^{-5}. For $T=1600$°K this x corresponds to a wave-length of about 4475A, since x_m for this temperature is 17,900A, approximately.

It should be mentioned that a few books do have the curves plotted correctly. In our examination we have found correct curves in Roberts' *Heat and Thermodynamics* and Crew's *General Physics*.

G. E. M. JAUNCEY
E. S. FOSTER, JR.

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A Simple Demonstration of the Effect of Intensity upon Pitch

IT is known[1] that a change in the intensity of a musical sound, without any change in frequency, may give rise to a change in pitch. The effect is a maximum in the neighborhood of 200 cycles/sec. Below some 2000 to 3000 cycles/sec. an increase in intensity lowers the pitch, and at higher frequencies an increase in intensity raises the pitch.

A simple demonstration of the effect may be obtained in the well-known resonance experiment in which use is made of two tuning forks of the same frequency. When one fork is struck vigorously and shortly afterward damped there is an abrupt drop in intensity, and at the same time a rise in pitch may be observed. This rise in pitch does not depend on which fork is struck, and it is greater than that which might be brought about by the very slight dependence of frequency upon amplitude.

The experiment may be varied by striking one fork vigorously while the other is sounding gently. At the instant when the vigorous blow is given there is an abrupt rise in intensity, and at the same time a slight drop in pitch. The change in pitch is especially evident if the ear is fairly close to the forks.

ARTHUR TABER JONES

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Northampton, Massachusetts.

[1] C. V. Burton, Phil. Mag. **39**, 447 (1895); H. Fletcher, J. Acous. Soc. Am. **6**, 59 (1934); S. S. Stevens, J. Acous. Soc. Am. **6**, 150 (1935).

Comprehensive Examinations in Physics

EXAMINATIONS should be prepared with definite objectives in view. When a professor sets out to examine his class in elementary physics he must have in mind some such question as "What should this course have done to and for the student?" Since the objectives of a course for engineers might be quite different from those of a course designed for nontechnical students it is natural that the examinations in the two courses should differ—not necessarily in difficulty, but in the nature of the questions. The present college physics testing program cannot take into account the objectives of all the various courses offered in the participating colleges but it nevertheless serves a useful purpose in supplying a basis of comparison on a national scale for the benefit of student and instructor. The results can be interpreted by each one in the light of his own objectives. It is important to remember that the comparative grades are significant only to the extent that the objectives are similar. It would be quite unfair to make the results of the examination available, to employers for example, because the interpretation of the grades with respect to the nature of the course offered would be impossible for an outsider.

It may be a little easier to get agreement among physicists as to the main objectives of a set of courses leading to a major in physics, than it is to do the same thing for an elementary course. If the objectives can be agreed upon it would seem to be an excellent thing to set up a national comprehensive examination in physics. But I should like to emphasize the difference between offering a national examination the result of which is used for the benefit of each student and his instructor (but which is not used against the student at least to any greater extent than to determine whether he passes or fails a course) and offering an examination upon which the whole future of the student may depend. In one case the instructor who knows the objectives and the limitations of the course to which the student has been exposed can use his discretion in interpreting the test results; in the other, some outsider, perhaps a prospective employer, interprets the result. It is evident that inadequacies or imperfections in the examination may be overlooked in the first case but not in the second.

I am very heartily in agreement with the suggestion that the American Association of Physics Teachers sponsor a national comprehensive examination in physics. There are several important contributions which such a program could make, as Professor Lapp has pointed out in the February, 1937 issue (p. 25). It would undoubtedly tend to improve the professional standing of physicists, would encourage both student and instructor to treat the subject of physics as an integrated whole, and would supply the student and his prospective employer with a gauge for indicating to some extent the student's prospects of success in a given job.

But to make these contributions the examination must be more than is suggested in Professor Lapp's proposal. It must do more than test the knowledge of the student in six or seven separate compartments; more even than test him in "general physics" which presumably will treat the overlapping problems of these compartments. It must treat the student's ability to use all of his powers in the solution of a problem which is not confined to one compartment. If it is a comprehensive examination which a student and employer may use in making an estimate of a student's possibilities it must have two characteristics not suggested in Professor Lapp's paper: (1) the objectives behind the examination should be clearly stated so that comparisons of grades are made in the light of those objectives; I suggest that before the comprehensive examinations plan is adopted the committee make a statement of objectives and submit it to physicists everywhere for their approval; (2) it should not be limited to the narrow bounds of one part of the subject, nor should it be kept strictly within the field of physics. No comprehensive test of a student's ability in physics can omit his knowledge in the boundary fields of chemistry, mathematics, engineering, etc.; his skill in looking up things in the literature; his ability to draw honest and reasonable conclusions from data; his ability to present the results of his study in a clear manner; and even his appreciation of the economic and social implications of his work.

It is much more difficult to prepare an examination that will do all of these things than one that will test knowledge in separate compartments; but it is naturally a bigger job to prepare a test upon which a student's future may depend than one which is to be used only for his guidance while in college. I would suggest that after suitable objectives have been outlined a series of tests be prepared which follow this larger outline:

Tests of Knowledge

Mechanics	General physics
Heat	German or French
Sound	Chemistry
Electricity and magnetism	Mathematics
	Engineering
Light	History
Modern physics	Economics

Tests of Skills

- Ability to use the facilities of the library
- Application of knowledge to problems in physics
- Ability to manipulate laboratory equipment
- Laboratory arts
- Design
- English ability: technical report writing; clear exposition in nontechnical terms
- Presentation of information in charts, curves, graphs, etc.
- Skill in interpreting data
- Ability to consider practical and theoretical aspects of a problem, including social and economic aspects
- Skill in handling personal situations
- Shop work
- Application of physics to engineering, biology, medicine, agriculture, architecture (choice)

Perhaps some of these, for example, the ability to manipulate laboratory equipment, cannot be tested in any direct way in an examination of national scope. In such cases, if the skill is an important element in the training of a physicist, it is not satisfactory merely to avoid testing it. It might be handled in one of two ways: (1) avoid testing it and then specifically indicate to anyone who uses the test results that it has been omitted; (2) get an indirect evaluation by asking the students' instructors and former instructors to rate him on the skill under consideration.

G. E. Owen

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Proposed Physics Examination at the Baccalaureate Level

I HAVE been giving the *Cooperative Physics Tests* for several years and have found them to be valuable for various reasons, among them the following: (1) they keep an instructor from running away with pet notions; (2) they encourage students to seek out and fill gaps in their training; (3) they help to place the instructor in the position of an ally to the students. Consequently, when I learned about the proposal to give a comprehensive examination in physics at the baccalaureate level, I received it with enthusiasm; it seems that such an examination should help instruction in advanced courses much as the "Cooperative Tests" have helped instruction in the elementary courses. I am in hearty agreement with the proposal as outlined by Professor Lapp in the February issue (p. 25), except that the month of May appears to me to be a better time for the examination than January.

WALDEMAR NOLL

Berea College,
Berea, Kentucky.

The Pythagorean Problem

THE problem of the infinite array of right triangles, the sides of which are integers, is well known to students of number theory; the solution is given in Chrystal's *Algebra*, Vol. II, p. 503, and elsewhere. The hypotenuse and one leg of each triangle are odd integers and the other leg is even; they are represented by r^2+s^2, r^2-s^2, and $2rs$, respectively, where r and s are integers which are prime to each other, one being odd and the other even.

The solution given by Bacon[1] is interesting because it directs attention to the fact that the triangles may be grouped according to the differences between any two of their sides. The rules which he employs in order to avoid producing triangles which are merely similar to each other are unnecessarily complex, because he has not made use of all of the conditions which are imposed on the sides. The complete solution follows.

Let a, b and c be the odd and even legs and the hypotenuse, respectively. Each set of values for them is subject to the conditions $c-a=m$, $c+a=b^2/m$, $c-b=n$, $c+b=a^2/n$, three of which are independent, in which m is an even and n an odd integer. From the first three conditions it follows that

$$c-m-n=b-m=a-n=(2mn)^{\frac{1}{2}}. \tag{1}$$

Since the right-hand member is an integer, the most general expression for m and n are $2x^2z$ and y^2z, or *vice versa*. Any factor common to m and n is common also to a, b and c. It follows that triangles similar to each other are avoided if the values of m and n are restricted to $2x^2$ and y^2, where x is any integer and y is an odd integer which is prime to x. This means that m may be any number in the sequence 2, 8, 18, 32, 50, 72, 98, $\cdots$, and n may be any number in the sequence 1, 9, 25, 49, $\cdots$ which is prime to the value selected for m. Eqs. (1) are employed to calculate the sides of the triangles. Table I of Bacon's paper[1] contains a few sets of values for low values of m and n.

The two solutions are not independent, but are so related that the numbers x and y are identical with s and $r-s$ in the conventional solution of the problem.

H. H. MARVIN

University of Nebraska,
Lincoln, Nebraska.

[1] Am. Phys. Teacher **4**, 197 (1936).

Solar Eclipse Expedition of the National Geographic Society

PROFESSOR F. K. Richtmyer, president of the American Association of Physics Teachers, is a member of the expedition sponsored by the National Geographic Society and the U. S. Navy to the Phoenix Islands to observe the total solar eclipse of June 8. The expedition will establish headquarters on either Canton or Enderbury Island, these two being the only islands within the entire 8800 miles of the path of totality near enough to the center of the band of totality to afford satisfactory conditions for observation. Professor Richtmyer will be in charge of the visual measurements of the total light of the corona for comparison with the radiation from the full moon. He will also measure the percentage of polarization at different distances from the sun's edge.

The other members of the expedition are as follows: Dr. S. A. Mitchell, director of Leander McCormick Observatory, University of Virginia, scientific leader; Captain J. F. Hellweg, superintendent of the U. S. Naval Observatory, who will have charge of the Navy's participation; Dr. Paul A. McNally, director of Georgetown College Observatory; Dr. Irvine C. Gardner, National Bureau of Standards; Dr. Theodore Dunham, Mt. Wilson Observatory; Richard H. Stewart, of the staff of the National Geographic Society; John W. Willis, U. S. Naval Observatory; and an engineer of the National Broadcasting Company.

A description of the eclipse will be broadcast from the island over a nationwide network and rebroadcast to foreign countries.

Reprints of Survey Articles for Class Use

REPRINTS of the following articles which have appeared in previous issues may be obtained at cost from the Editor, Columbia University, New York, N. Y.: Houston, "The Physical Content of Quantum Mechanics," 50 cts.; Barnes and Bonner, "The Early History and the Methods of Infrared Spectroscopy," 60 cts.; Grondahl, "Copper-Oxide Rectifiers and Their Applications," 40 cts.; Nordheim, "Present Conceptions of the Metallic State," 30 cts.; Curtis, "Principles Involved in Determining the Absolute Values of the Electrical Units," 50 cts. The prices quoted are for 6 copies postpaid.

Teaching Aids

Monographs and Pamphlets

The Present Status of Ferromagnetic Theory. R. M. Bozorth, Bell Telephone Laboratories Monograph B-911. 29 p., 25 figs., 2 tables, 15×23 cm. *Bell Telephone Laboratories* (463 West St., New York), gratis. A reprint of an up-to-date and authoritative summary which appeared in *Electrical Engineering* and in *The Bell System Technical Journal*. The reprints which are issued from time to time in this valuable monograph series are regularly distributed gratis to some 165 American colleges.

Bell Telephone Laboratories. The following pamphlets may be obtained gratis for departmental libraries from the Bureau of Publications, Bell Telephone Laboratories, 463 West St., New York, N. Y.

Pictures from Bell Telephone Laboratories. 48 p., 42 photographs. Show the laboratories and various types of experimental work carried on.

The Bell System Historical Museum. 50 p., 72 photographs. An excellent description of historical apparatus in the Museum at the Laboratories.

Official Handbook of Exhibits in the Division of the Basic Sciences, Century of Progress Exposition. 184 p., 32 fig., 15×23 cm. This handbook describes briefly each of the numerous exhibits in the Hall of Science at the Chicago Exposition of 1934. It contains many suggestions and ideas of value to those who are interested in science museums and demonstrations. The Central Scientific Co., Chicago, has acquired a limited number of copies and will send one to any teacher for 12 cts. in stamps, to cover mailing costs.

The Photronic Photoelectric Cell. 73 p., 42 fig. Monograph B-8. *Western Electrical Instrument Corporation* (Newark, N. J.), gratis. A useful manual for teachers on the "Photronic" cell, and on photoelectric principles and applications. Ten experiments are described.

Yesterday and Today in Refrigeration; Lord Kelvin, Master of Heat and Cold. *Temperature Research Foundation of Nash-Kelvinator Corp.* (420 Lexington Ave., New York), gratis. The first of these two booklets gives a brief factual survey of the history and principles of refrigeration; the second contains a biography of Kelvin.

Technology and Employment, and Machine-Made Jobs. *Machinery and Allied Products Institute* (221 N. La Salle St., Chicago), gratis. Three pamphlets which present facts and arguments to show that technological advancement always tends to increase the total number of jobs available.

General Motors Publications. *General Motors Co.*, (Research Lab. Sec., Technical Data Dept., Detroit), gratis:

Transportation Progress. 53 p., 12 fig. The history of self-propelled vehicles since earliest times.

Research—An Eye to the Future, 39 p., 11 fig. A popular account of the role of research in the automobile industry.

How to Park in a Tight Place, 4 p., 4 fig.

We Drivers. 36 p., 21 fig. Gives many valuable hints for safe driving.

Charts and Posters

Automobile Wall Charts. General Motors Co. (Research Lab. Sec., Technical Data Dept., Detroit), gratis. Three new diagrams, similar in value and character to those described in Am. Phys. Teacher **5**, 95 (1937):

This Question of Cylinders, 59×89 cm. Shows the relations of the power strokes in 4-cycle engines having various numbers of cylinders.

Mechanical Servants, 59×89 cm. A striking diagram showing the successive steps in the functioning of a "starterator" and automatic choke.

The "Shorthand" of Highway Signs, 39×58 cm. Conventional traffic symbols and their meanings.

* * *

Appointment Service

REPRESENTATIVES of departments or of institutions having vacancies are urged to write to the Editor, Columbia University, for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the permission of the institution concerned.*

12. Ph.D. Cornell, B.S. Bowdoin College. Age 38, married. 11 yr. teaching in both men's and women's colleges in East and South. Research in electron physics. Special interest in development of demonstration lectures, laboratory experiments and equipment. Glass blowing.

13. Ph.D. Cornell. Age 31, married, 2 children. 4 yr. college teaching. 5 yr. full-time research in x-rays. Primarily interested in college teaching and research. Hobbies: photography, geology, music.

14. Ph.D. Chicago, B.S. Bradley Polytechnic, with minors in math. and chem. Age 25, married. 4 yr. laboratory and teaching assistant, Chicago. Research, Faraday effect at high frequencies.

15. Ph.D. Iowa State, B.S. in E.E. Minnesota. Age 33, unmarried. 5 yr. sales and research engineer; 4 yr. teaching fellow, physics. Research, effect of gas on metal surfaces used for electron recording, etc. Interested in teaching.

16. Ph.D. Indiana. Age 38, married, 2 children. 6 yr. college teaching. Research in acoustics. Trained for teachers college or university position Interested in teaching, laboratory development, and research.

17. Man, age 39, married, 1 child, Protestant. Ph.D. Univ. of Pittsburgh. 14 yr. teaching undergraduate physics; 5 yr. asst. prof., important eastern university. Desires professorship in medium sized progressive college; available fall 1937.

18. Ph.D. Penn. State. Age 36, married. 11 yr. college teaching experience. Prepared to teach and interested in developing strong courses in advanced mechanics, heat, electricity, and modern physics as well as elementary physics. Desires assistant professorship where there is an opportunity to progress and develop.

19. Man, age 32, married, 1 child. Ph.D. Minnesota. Head of physics dept., junior college, 2 yr.; industrial research, Bell Telephone Laboratories, 1 yr. Has taught both physics and astronomy. Interested in teaching or research in a college or in an industrial laboratory.

Any member of the American Association of Physics Teachers who is not employed in a capacity that makes use of his training in physics may register for this appointment service and have a "Position Wanted" announcement published without charge.

Recent Publications

Reference Books for the Elementary Course

The Story of Bridges. Archibald Black. 242 p., 66 photographs, 15×23 cm. *McGraw-Hill*, $2.50. An interesting, nontechnical story of all types of bridges and bridge building from the first primitive log and vine structures to the modern spans involving unusual engineering problems. Excellent material and photographs. The author is a special writer for the Port of New York Authority.

Weather Rambles. W. J. Humphreys, U. S. Weather Bureau. 269 p., 37 fig., 13×19 cm. *Williams & Wilkins*, $2.50. "A book of prairie twisters, murmuring forest, roaring mountains; of the music and the beauty that is in winter; of rains and snows and floods; of air and sunshine and starshine; of much that is odd and interesting about weather, good and bad." Elementary, interesting and sound.

An Outline of First Year College Physics. Clarence E. Bennett, Assistant Professor of Physics, University of Maine. Rev. ed. 203 p., 117 fig., 14×21 cm. *Barnes & Noble*, paper, 75 cts. In the new edition of this review or "self-help" outline, many commendable improvements and corrections have been made, and a brief glossary of terms, a summary of laws and principles, and a supplementary set of general review questions have been added. It is the best outline of this kind that we have seen.

Down to Eearth—An Introduction to Geology. Carey Croneis and William C. Krumbein, Department of Geology, University of Chicago. 519 p., 64 plates, 17×23 cm. *Univ. of Chicago Press*, $3.75. This text was designed for the geology portion of the new plan physical science course at the University of Chicago. The relations of geology to the other sciences are stressed. There are many diagrams and sketches, and 64 pages of rotogravure pictures that represent an innovation in textbook illustration.

Highlights of Astronomy. Walter Bartky, Associate Professor of Astronomy, University of Chicago. 288 p., 29 plates, 17×23 cm. *Univ. of Chicago Press*, $2.50. In this text for the astronomical portion of the Chicago new plan physical science course, stress is placed on the interpretation of phenomena in the light of everyday experience. Available with the book is an instrument, designed by the author and costing $2, through which the reader views sky charts or films; these superimposed on the sky, make possible identifications of the constellations.

The Handmaiden of the Sciences. Eric T. Bell, Professor of Mathematics, California Institute of Technology. 224 p., 34 fig., 14×22 cm. *Reynal & Hitchcock*, $2. A book for the intelligent laymen on the services that mathematics has rendered to the physical sciences and through them to mankind. The material is excellent and is well put together by a distinguished mathematician and author who understands the natural sciences. Interesting as the book is, it is not written with as much inspiration as the author's *Queen of the Sciences;* one is left with the feeling that in spite of the important aid that mathematics has been to the sciences, it only emerges into its full beauty and proper sphere when it is considered as mathematics itself.

General Education

How to Use the Educational Sound Film. M. R. Brunstetter, Teachers College, Columbia University. 187 p., 31 figs. and charts, 15×22 cm. *Univ. of Chicago Press*, $2. The uses of the sound film in school classrooms are discussed from the standpoint of practical experience.

The College of the Future. Mowat G. Fraser, lecturer in the Philosophy and History of Education, University of Michigan. 549 p., 15×23 cm. *Columbia Univ. Press*, $3.75. More than 100 American colleges and universities are proclaiming distinctive "plans," and educators are disagreeing both on basic policies and on the method for determining which policies are sound. The purpose of this book is to give a comprehensive survey of the wide range of conflicting fundamental plans and trends, and to develop and illustrate a procedure for making a sound appraisal of them.

The Teaching of Controversial Subjects. Edward L. *Thorndyke*, Teachers College, Columbia University. 42 p., 11×17 cm. *Harvard Univ. Press*. $1. This is the 1937 Inglis Lecture in Secondary Education. The thesis is that if controversial questions are treated in the schools as stimuli to learning fundamentals and taking the advice of experts, and as for occasions for practice in the scientific treatment of probabilities and weightings, then they can do nothing but good, though they probably will not do so much good per unit of time and effort as questions whose answers can be demonstrated by crucial observations, experiments, and statistics. Although controversial questions probably should be used rather sparingly, competent teachers in the schools should be permitted, and even encouraged, to plan scientific treatments of them; like everything else in education, such work should be judged by its results.

Professor at Bay. Burgess Johnson. 251 p., 13×19 cm. G. P. Putnam's Sons, $2. Thirty fragmentary essays on axioms, democracy, absent-minded professors, reincarnation, joiners, manners and morals, hospitality, whittling, -isms in art, conversation, campus against classroom, and divers other matters nonsensical and serious. There is some back talk at the politician and the man in the street who have been baiting the professors. In the course of all this the author, who is a professor in Union College and a former journalist, seeks a philosophy to guide him in his teaching. A thoroughly delightful book.

DIGEST OF PERIODICAL LITERATURE

History

Twelve notable American inventions. Anon; *Nature* **138**, 1088, Dec. 26, 1936. In connection with the centenary of the U. S. Patent Office, the following list was compiled of the 12 inventions that have done most to change life in America: the telephone, by Bell; the electric telegraph, by Morse; the electric light, motion pictures, and the phonograph, by Edison; the commercial steamboat, by Fulton; the airplane, by Wilbur Wright; the airbrake, by Westinghouse; the sewing machine, by Howe; the cotton gin, by Whitney; the vulcanization of rubber, by Goodyear; a practical reaping machine, by McCormick; and the manufacture of aluminum, by C. M. Hall.

Physics Education

Mathematical difficulty in college physics. K. F. Oerlein; *Math. Teacher* **30**, 125–127, Mar. 1937. That success or failure in physics rests to a large degree on the mathematical preparation of the students is no longer a supposition. As to the causes of this difficulty, there appear to be but three reasonable possibilities: (1) the mathematics used in the physics course may be more than the student has had; (2) the student may have received credit for sufficient mathematics but not have mastered it; (3) the mathematics situations encountered in physics may be so different from those learned in the mathematics class that the student is unable to recognize them without assistance.

With regard to the first possibility, studies made on both the college and the secondary school levels show that, in general, the student has been exposed to all the mathematics needed for general physics. For example, the author's investigation of 379 first courses in college physics in 211 institutions revealed that the mathematics implied by the stated requirements for admission was adequate for the work done in the courses. If a teacher uses more mathematics than that implied by the stated prerequisites, the responsibility for student failure rests squarely with him. But he has a right to expect that students with credit in the prescribed mathematics will be able to use it without too great a strain. Evidence indicates that, on the whole, physics teachers have gauged the mathematical needs for their courses correctly and have kept within the limits implied by the mathematics accredited to their students.

As for the second possibility, many studies have revealed the relatively low degree of mastery of mathematics by students [e.g., see Lueck, Am. Phys. Teacher 2, 18 (1934)]. It would be unjust to indict mathematics teachers as a whole for this situation, for they are probably as efficient as any other group. The criticism is more properly directed at the content of their courses, the lack of integration of the various courses, and, most important, the lack of coordination with related fields. Mathematics, like physics and other subjects, is not an end in itself for most people; and since the learning of physics, for whatever purpose, depends so largely on the mathematical preparation, it is the duty of mathematics teachers to modify their courses so as to conform more nearly to the needs of those using it.

With regard to the third possibility, elaborate studies have shown how closely mathematical concepts, processes and methods of procedure are interwoven with the physics in textbooks. The author, for example, studied 72 local manuals from 61 colleges and found that laboratory physics is even more quantitative than textbooks. Yet the number of mathematical items was not large. The manuals furnished abundant examples of the *functionalized* concept of mathematics. Summing up, two words characterize the mathematics in the manuals; it is analytic and functional. Evidence is thus accumulating that there is considerable truth in the third possibility. The actual number of mathematical items used in first year physics is much smaller than one would think; but, although these relatively fewer items occur many times over, changed physical settings require changed mathematical forms.

Here, then, lies the crux of the problem. Too much, rather than too little mathematics has been taught. *To teach for real mastery, fewer items, carefully selected on the basis of use, without regard for the formal divisions of mathematics, might well be the aim of a thorough revision of secondary school mathematics.* As a matter of fact the *Ninth Yearbook* of the National Council of Teachers of Mathematics contains such a course based upon the functional concept of mathematics, which, if put into practice, would delight the heart of any physics teacher. Most discouraging, however, is the general attitude of mathematics teachers toward these revisions in their field.

There is no intention here of releasing physics teachers from some responsibility for student failure arising from the mathematical nature of the course; they must continue to assist students in making the necessary transfer of their general mathematical knowledge to specific physical situations. Just where this general information should end and transfer begin is a matter calling for a most sympathetic and close cooperation between the two departments. How much longer can an artificial departmentalization forestall such a natural cooperative movement?

This article is based on work that was sponsored by the "Committee on Mathematical Preparation of Students" of the American Association of Physics Teachers.

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The American Institute of Physics is a membership corporation of which five societies are the founding members. These five societies are the principal national societies devoted to pure and applied physics in America. Their names, and those of their representatives who form the Governing Board of the Institute, are given above. The principal work of the Institute is the publication of journals sponsored by the societies or by itself. The names and the editors of the journals are also listed above.

The broad purpose of the Institute is to represent, in all matters of wide or common interest, the five thousand or more members and subscribers associated with the Founder Societies and the journals. It aims to advance the science and profession of physics, and to promote cooperation between pure research, the applied sciences and the industries. To achieve these aims, it is greatly in need of an endowment and is empowered by law to administer grants and funds of any kind.

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